DCE-14

14 January 1997

Data Report

Dielectric Properties of

Landmine Fillers (Waxes and Sands)

Prepared for:
Regina Dugan
U.S. Department of Defense
Advanced Research Projects Agency (ARPA)
3701 North Fairfax Drive
Arlington, VA 22203-1714
703-696-2296

Prepared by:
John O. Curtis
U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Clifton, Peggy

From: George, Vivian Ms PM-MCD [vivian.george@nvl.army.mil]
Sent: Friday, April 27, 2001 9:27 AM
To: 'Clifton, Peggy'
Subject: RE: Distribution on DARPA/Walcoff Documents & Data

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-----Original Message-----
From: Clifton, Peggy [mailto:pclifton@dtic.mil]
Sent: Wednesday, April 11, 2001 9:50 AM
To: 'Vivian George'
Subject: Distribution on DARPA/Walcoff Documents & Data

Vivian,

I am putting in the background clutter data documents and discs; some are marked "Approved for public release, distribution is unlimited," but others have no markings for distribution. Are they all unlimited distribution? If, not we will have to figure out what the distribution levels are for the unmarked documents. TIA,

Peg Clifton

Margaret Clifton
Nonprint Program Manager
Defense Technical Information Center
703.767.9085
pclifton@dtic.mil

"Civilization advances by extending the number
of important operations which we can perform without thinking about them."
-Alfred North Whitehead

Introduction

This report contains dielectric property measurement results for five different materials that have been used as fillers for various inert landmines. The original data were collected in the form of the real and imaginary parts of the complex dielectric constant versus frequency utilizing a Hewlett-Packard 8510C Vector Network Analyzer System with an S-Parameter Test Set and a coaxial sample holder. Software developed at the U.S. Army Engineer Waterways Experiment Station was used to convert S-parameter measurements at selected frequencies into a complex dielectric constant. The materials were assumed to be nonmagnetic. Other useful electromagnetic properties were calculated from the dielectric constant and frequency, including an equivalent electrical conductivity, the loss tangent, power attenuation, and a normalized phase velocity. The section entitled, "Fundamental Relationships," contains the formulae used to calculate these properties. Additional physical parameters of the samples that are included in the report include their dry density, volumetric moisture content, and temperature.

For additional details on how the data were collected, please contact me at the U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, (voice: 601-634-2855, FAX: 601-634-2732, e-mail: curtisj@ex1.wes.army.mil).

Filler Materials

Five different mine surrogate filler materials were acquired for these measurements. They consisted of three different waxes and two different sands. A red wax filler from an M19 surrogate and a yellow wax filler from a PMN surrogate were obtained from Mr. Steve Pranger, an employee of the Structures Laboratory at WES. A sample of a white wax used in M14 surrogates was obtained from Mr. A. Trang at the Countermine Directorate of the US Army Night Vision Laboratory. Locally-purchased sands were used by WES personnel to fill some mines used for field tests at Fort Carson, CO, and at Fort A.P. Hill, NJ. The Fort Carson sand was poorly-graded, clean, had a pinkish-white color, and was identified as a sand used for sand blasting. The sand used for the Fort A.P. Hill trials was well-graded, clean, with a yellowish color, and was labeled as a masonry sand.

Fundamental Relationships

Assuming plane harmonic wave propagation in a lossy, non-magnetic, unbounded medium, the wave amplitude function may be written:

$$e^{i(kx - \omega t)}$$

where

k $= \beta + i\alpha$ $= \omega N/c$

is the complex propagation constant,

β is the phase constant,

α is the amplitude attenuation factor,

ω is the radial frequency,

N is the complex index of refraction,

c is the velocity of light in a vacuum,

i is the symbol designating an imaginary quantity = $\sqrt{-1}$,

x is a space coordinate, and

t is time.

Furthermore,

$$N^2 = \epsilon = \epsilon' + \epsilon''$$

where ϵ is the relative complex dielectric constant, which, along with the electrical conductivity from Ohm's Law, represents the electrical properties of the medium. The interpretation of these properties as used in this study is that the conductivity, σ , accounts for current due to free charged particle motion, while the imaginary part of the complex dielectric constant, ϵ'' , accounts for displacement current losses (those due to the electric polarization of the medium). When both conduction and displacement currents are considered, one finds two terms in Ampere's law for current flow that represent losses (or a shift in phase), one containing the electrical conductivity and one containing the imaginary part of the dielectric constant. While these two terms account

for different loss mechanisms, most researchers use only one term or the other to identify losses, with many users preferring to deal with the concept of electrical conductivity. In MKS units, the relationship between the two quantities is taken to be

$$\sigma = \epsilon'' \epsilon_0 \omega$$

where the units of conductivity are mhos/meter (or siemens/meter) and ϵ_0 is the permittivity of free space (8.85×10^{-12} farads/meter).

Squaring the expression for the complex propagation constant, substituting the expression for the square of the complex index of refraction, and equating real and imaginary components, one obtains two algebraic equations that relate the amplitude attenuation factor and phase constant to the complex dielectric constant:

$$\beta^2 - \alpha^2 = \frac{\omega^2}{c^2}\epsilon'$$

and

$$\alpha\beta = \frac{\omega^2 \epsilon''}{2c^2}$$

Solving these equations for the amplitude attenuation factor and for the phase constant results in the following expressions:

$$\alpha = \frac{\omega}{c}\left(\frac{\epsilon'}{2}\left(\sqrt{1 + \left(\frac{\epsilon''}{\epsilon'}\right)^2} - 1\right)\right)^{1/2}$$

and

$$\beta = \frac{\omega}{c}\left(\frac{\epsilon'}{2}\left(\sqrt{1 + \left(\frac{\epsilon''}{\epsilon'}\right)^2} + 1\right)\right)^{1/2}$$

The ϵ''/ϵ' ratio is also referred to as the loss tangent. Some researchers prefer to work with the electrical conductivity in place of the dielectric loss term.

Plane waves of constant phase will propagate with a velocity

$$v = \frac{\omega}{\beta} = c\left(\frac{\epsilon'}{2}\left(\sqrt{1 + \left(\frac{\epsilon''}{\epsilon'}\right)^2} + 1\right)\right)^{-1/2}$$

This phase velocity is not necessarily the speed with which the energy of the wave propagates through the medium. The latter is referred to as the group velocity and can be calculated as the rate of change of radial frequency with respect to the phase constant. However, as long as the phase velocity is relatively constant over the range of frequencies of interest, then there is little difference between phase velocity and group velocity.

The power intensity of the plane electromagnetic wave decreases exponentially with depth of penetration by the factor, $e^{-2\alpha x}$, or, in one unit of distance traveled, a decrease of $e^{-2\alpha}$. Power attenuation expressed in decibels per meter can then be written as:

$$PL = -8.6859 \frac{\omega}{c} \left(\frac{\epsilon'}{2} \left(\sqrt{1 + \left(\frac{\epsilon''}{\epsilon'} \right)^2} - 1 \right) \right)^{1/2}$$

Experimental Procedures

The experimental procedure used to collect electrical property data for the waxes consisted of the following steps. First of all, the mass of the brass coaxial sample holders used in the experimental apparatus were measured. The holders have a square cross section and a removable cover that allows the experimenter to easily fill the holder with either liquid or fine granular materials. Pieces of the wax were then melted and poured into the holder cavity. Next, the mass of the combined holder and sample was measured. Knowing the volume of the sample holders from previous measurements, allows one to calculate the density of the wax sample. The holder, sample, and cover plate were then placed in a temperature control device and connected to the S-parameter test set. After the sample reached the desired temperature, data were collected over the selected range of frequencies.

As for the sands, a sample was first taken from the source container and packed into the sample holder using small spoons and other utensils. The sand was packed as tightly as possible at whatever moisture content it possessed in the bags, meaning that there was no control over sample dry density. After the collection of a set of data at nominally-dry conditions, the sample was wetted by the addition of distilled, deionized water. After allowing some time for the added moisture to fully penetrate any clay-size minerals, the electrical properties were once again measured. Sample and holder masses were recorded prior to each measurement. Following the last data collection, the sand was scraped and flushed from the sample holder and dried in an oven to obtain its dry mass, which, by virtue of knowing the sample volume, leads to the sample dry density and the calculation of sample volumetric moisture contents for each measurement. Of course, these data can also be used to calculate the commonly used weight-based moisture content as well.

Data Presentation

The following pages contain all of the electrical property data associated with these landmine filler materials. For each material one will find a table of measured and calculated parameters. The first column of these tables lists the frequencies at which the measurements were made. The last six columns list the real and imaginary components of the measured relative complex dielectric constant, the equivalent conductivity (in mhos per meter), the loss tangent, the power attenuation factor in decibels per meter, and the normalized phase velocity. Following each table one will find plots of these six parameters versus frequency.

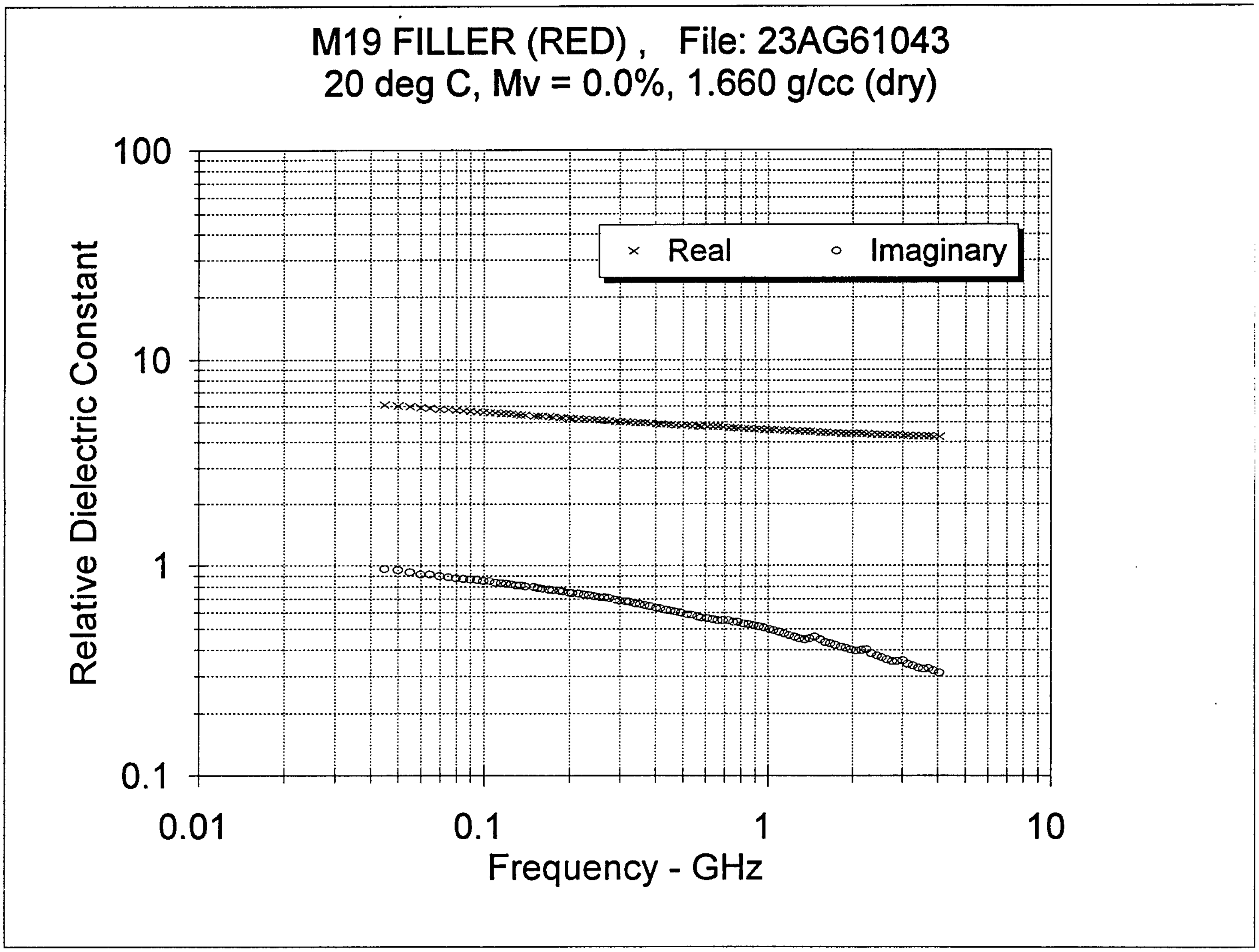
The results of these measurements are exactly as expected except for the M19 red wax filler. Obviously, from the measured density, it is safe to say that this substance is a combination of wax and some other material(s). The real part of the relative dielectric constant for most waxes is in the range of 2-3 (as was true for both the white and yellow waxes), and the loss tangent is usually very small. The M19 filler had a permittivity in the range of 4-6 and a loss tangent on the order of 0.1. This indicates the presence of either molecules with a finite dipole moment or free charged particles.

Any anomalies in the frequency response of these materials is attributable to one of two factors. First of all, the measurement procedure is somewhat sensitive for materials having low values of the dielectric loss tangent. Secondly, the measurements will sometimes exhibit anomalous behavior near frequencies that represent multiples of half wavelengths in the sample materials. For example, see the break in the imaginary part of the dielectric constant in the wet Fort Carson sand sample at about 350 MHz. The phase velocity at that frequency is about 0.72×10^{8} meters per second, meaning that the wavelength in the sample is about 0.2 meters. In other words, that particular sample supports about one-half of a wavelength at that frequency (the sample is 10 centimeters long).

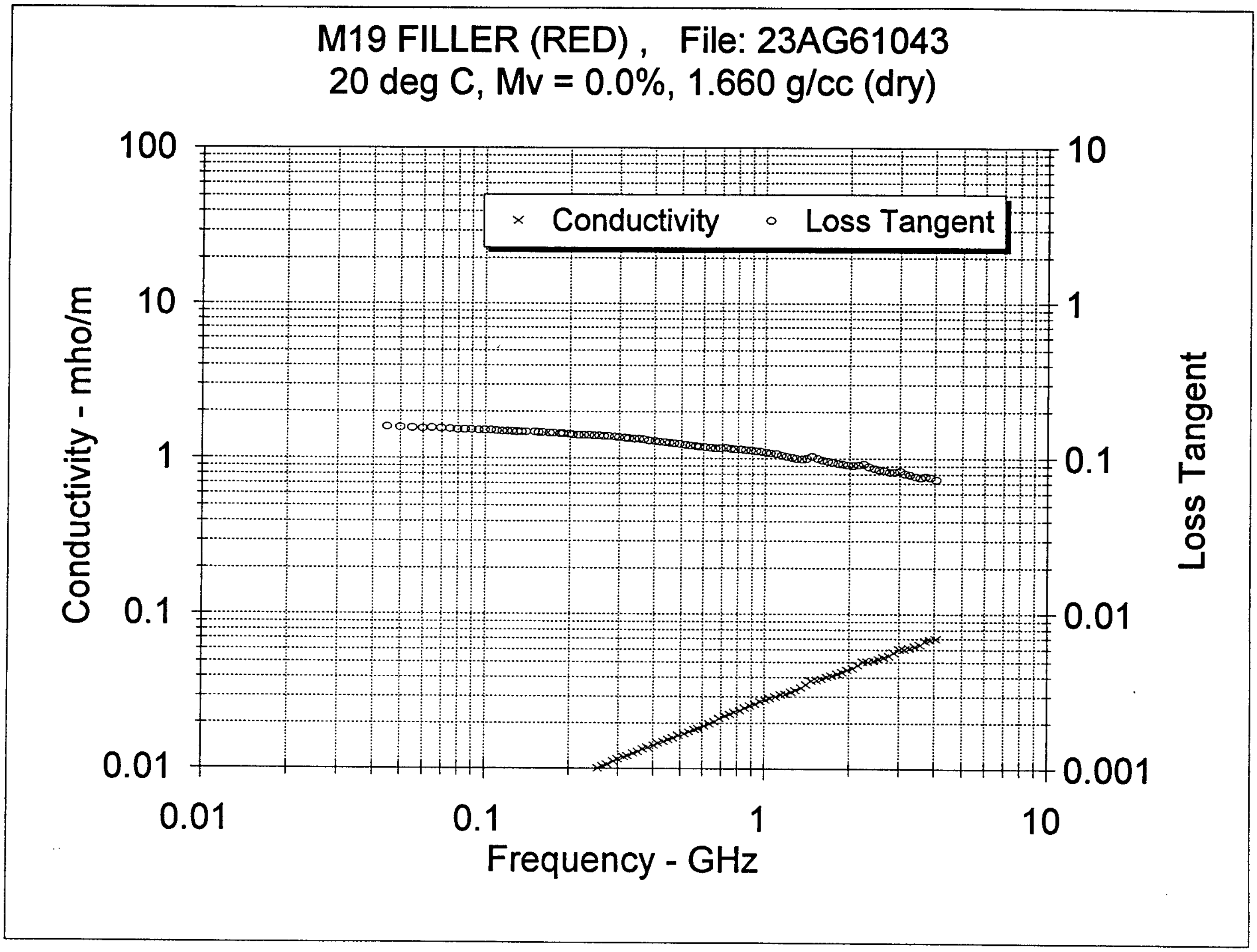
23AG61043
M19 Filler (Red)
9.7
4 M19 FILLER (RED) , File: 23AG61043
0 20 deg C, Mv = 0.0%, 1.660 g/cc (dry)
20
1.66

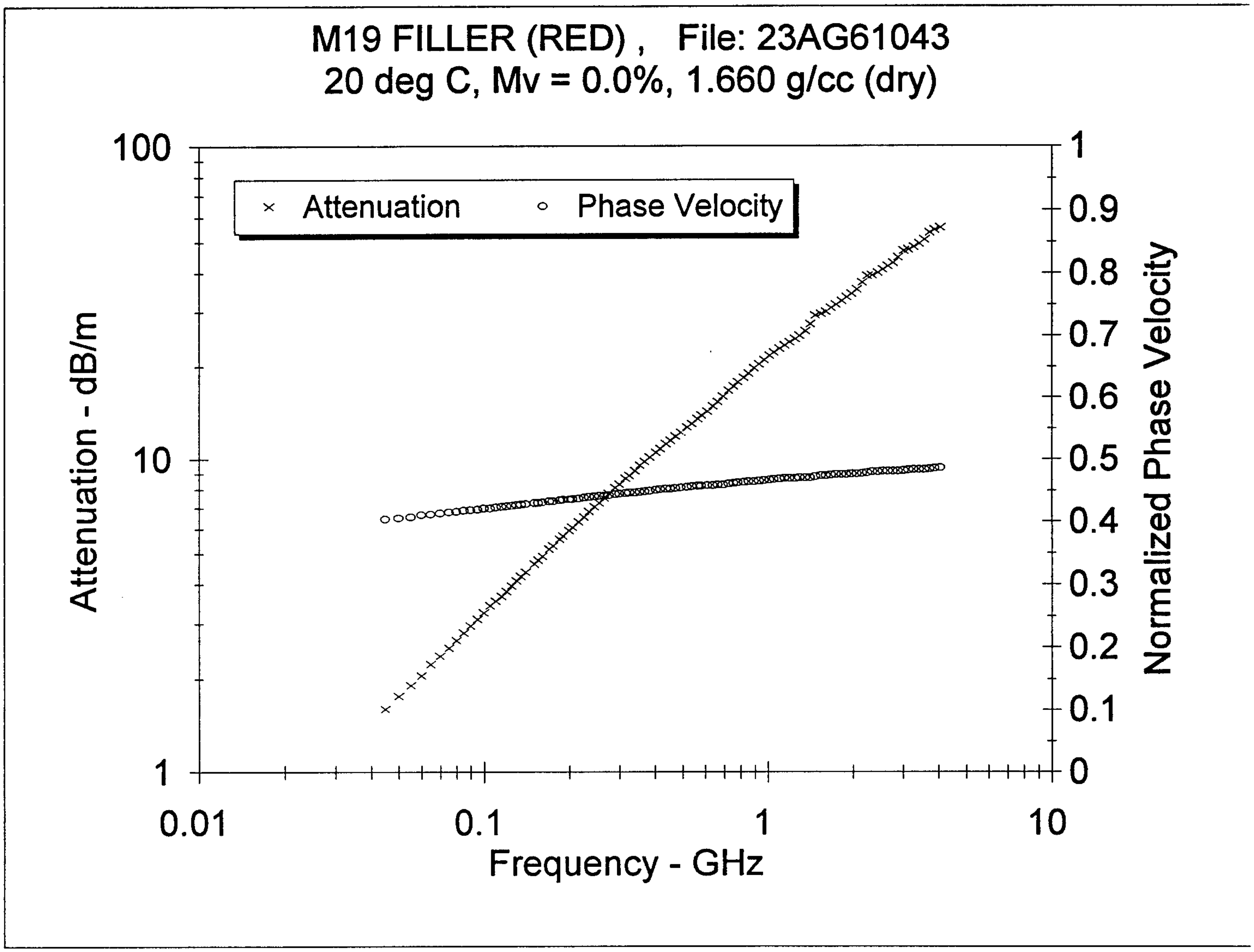
Freq GHz	Re(eps)	Im(eps)	Cond mho/m	Loss Tan	Attn dB/m	Norm Vel
0.045	6.07	0.97	0.0024	0.16	1.60	0.40
0.050	6.01	0.95	0.0027	0.16	1.76	0.41
0.055	5.94	0.93	0.0028	0.16	1.91	0.41
0.060	5.87	0.91	0.0030	0.16	2.04	0.41
0.065	5.84	0.91	0.0033	0.16	2.23	0.41
0.070	5.79	0.90	0.0035	0.15	2.36	0.41
0.075	5.75	0.89	0.0037	0.15	2.51	0.42
0.080	5.71	0.87	0.0039	0.15	2.65	0.42
0.085	5.68	0.87	0.0041	0.15	2.81	0.42
0.090	5.64	0.86	0.0043	0.15	2.96	0.42
0.095	5.62	0.86	0.0045	0.15	3.11	0.42
0.100	5.59	0.85	0.0047	0.15	3.25	0.42
0.105	5.57	0.85	0.0050	0.15	3.43	0.42
0.110	5.53	0.84	0.0051	0.15	3.54	0.42
0.115	5.51	0.83	0.0053	0.15	3.67	0.42
0.120	5.49	0.82	0.0055	0.15	3.82	0.43
0.125	5.46	0.82	0.0057	0.15	3.96	0.43
0.130	5.44	0.81	0.0059	0.15	4.10	0.43
0.135	5.42	0.81	0.0061	0.15	4.25	0.43
0.140	5.40	0.80	0.0062	0.15	4.37	0.43
0.150	5.37	0.79	0.0066	0.15	4.65	0.43
0.155	5.35	0.79	0.0068	0.15	4.78	0.43
0.160	5.33	0.78	0.0070	0.15	4.91	0.43
0.170	5.30	0.77	0.0073	0.15	5.17	0.43
0.175	5.29	0.77	0.0075	0.15	5.31	0.43
0.185	5.26	0.76	0.0078	0.14	5.56	0.44
0.190	5.24	0.76	0.0080	0.14	5.70	0.44
0.200	5.22	0.75	0.0083	0.14	5.95	0.44
0.205	5.20	0.74	0.0085	0.14	6.06	0.44
0.215	5.18	0.74	0.0088	0.14	6.32	0.44
0.225	5.16	0.73	0.0091	0.14	6.57	0.44
0.235	5.14	0.72	0.0095	0.14	6.82	0.44
0.245	5.12	0.72	0.0098	0.14	7.05	0.44
0.255	5.10	0.71	0.0101	0.14	7.30	0.44
0.265	5.08	0.71	0.0104	0.14	7.55	0.44
0.275	5.06	0.70	0.0107	0.14	7.79	0.44
0.290	5.04	0.69	0.0112	0.14	8.13	0.44
0.300	5.02	0.69	0.0115	0.14	8.35	0.45
0.315	5.00	0.68	0.0119	0.14	8.69	0.45
0.325	4.98	0.67	0.0122	0.14	8.89	0.45
0.340	4.96	0.67	0.0126	0.13	9.21	0.45
0.355	4.95	0.66	0.0130	0.13	9.56	0.45
0.370	4.93	0.65	0.0134	0.13	9.84	0.45
0.385	4.91	0.64	0.0138	0.13	10.15	0.45
0.405	4.89	0.63	0.0143	0.13	10.55	0.45

0.420	4.88	0.63	0.0147	0.13	10.84	0.45
0.440	4.86	0.62	0.0151	0.13	11.22	0.45
0.455	4.84	0.61	0.0155	0.13	11.50	0.45
0.475	4.83	0.61	0.0160	0.13	11.88	0.45
0.495	4.81	0.60	0.0165	0.12	12.26	0.46
0.520	4.79	0.59	0.0170	0.12	12.71	0.46
0.540	4.78	0.58	0.0175	0.12	13.05	0.46
0.565	4.77	0.58	0.0181	0.12	13.51	0.46
0.585	4.76	0.57	0.0185	0.12	13.87	0.46
0.610	4.74	0.56	0.0191	0.12	14.32	0.46
0.640	4.73	0.56	0.0198	0.12	14.87	0.46
0.665	4.72	0.55	0.0204	0.12	15.33	0.46
0.695	4.71	0.55	0.0213	0.12	16.00	0.46
0.725	4.69	0.55	0.0222	0.12	16.74	0.46
0.755	4.67	0.54	0.0228	0.12	17.23	0.46
0.785	4.66	0.54	0.0235	0.12	17.78	0.46
0.820	4.64	0.53	0.0242	0.11	18.38	0.46
0.855	4.63	0.53	0.0251	0.11	19.03	0.46
0.895	4.61	0.52	0.0260	0.11	19.74	0.46
0.930	4.60	0.52	0.0267	0.11	20.32	0.47
0.970	4.58	0.51	0.0275	0.11	20.98	0.47
1.015	4.57	0.50	0.0284	0.11	21.67	0.47
1.055	4.55	0.49	0.0290	0.11	22.19	0.47
1.100	4.54	0.49	0.0298	0.11	22.84	0.47
1.150	4.53	0.48	0.0305	0.11	23.43	0.47
1.195	4.52	0.47	0.0311	0.10	23.93	0.47
1.250	4.51	0.46	0.0319	0.10	24.56	0.47
1.300	4.50	0.45	0.0327	0.10	25.16	0.47
1.360	4.49	0.45	0.0339	0.10	26.09	0.47
1.415	4.49	0.45	0.0356	0.10	27.41	0.47
1.475	4.47	0.46	0.0377	0.10	29.18	0.47
1.540	4.44	0.45	0.0382	0.10	29.61	0.47
1.605	4.43	0.43	0.0387	0.10	30.05	0.47
1.675	4.42	0.43	0.0397	0.10	30.83	0.47
1.745	4.41	0.42	0.0407	0.10	31.69	0.48
1.820	4.40	0.41	0.0419	0.09	32.60	0.48
1.900	4.39	0.41	0.0430	0.09	33.50	0.48
1.980	4.39	0.40	0.0441	0.09	34.39	0.48
2.065	4.38	0.40	0.0454	0.09	35.47	0.48
2.155	4.37	0.40	0.0478	0.09	37.31	0.48
2.250	4.35	0.40	0.0501	0.09	39.26	0.48
2.345	4.34	0.38	0.0501	0.09	39.35	0.48
2.445	4.33	0.37	0.0509	0.09	39.99	0.48
2.550	4.32	0.37	0.0521	0.09	40.96	0.48
2.660	4.31	0.36	0.0533	0.08	41.97	0.48
2.775	4.31	0.35	0.0547	0.08	43.07	0.48
2.890	4.31	0.35	0.0569	0.08	44.84	0.48
3.015	4.29	0.36	0.0597	0.08	47.15	0.48
3.145	4.28	0.34	0.0601	0.08	47.48	0.48
3.280	4.27	0.34	0.0612	0.08	48.43	0.48
3.420	4.26	0.33	0.0626	0.08	49.57	0.48
3.570	4.26	0.32	0.0644	0.08	50.96	0.48
3.720	4.25	0.33	0.0679	0.08	53.80	0.48
3.880	4.24	0.32	0.0690	0.08	54.83	0.49
4.045	4.23	0.31	0.0700	0.07	55.61	0.49



M19 FILLER (RED) , File: 23AG61043
20 deg C, Mv = 0.0%, 1.660 g/cc (dry)
Real
Imaginary
Relative Dielectric Constant
100
10
1
0.1
0.01
0.1
1
10
Frequency - GHz


M19 FILLER (RED) , File: 23AG61043
20 deg C, Mv = 0.0%, 1.660 g/cc (dry)
Conductivity
Loss Tangent
Conductivity - mho/m
100
10
1
0.1
0.01
Loss Tangent
10
1
0.1
0.01
0.001
0.01
0.1
1
10
Frequency - GHz

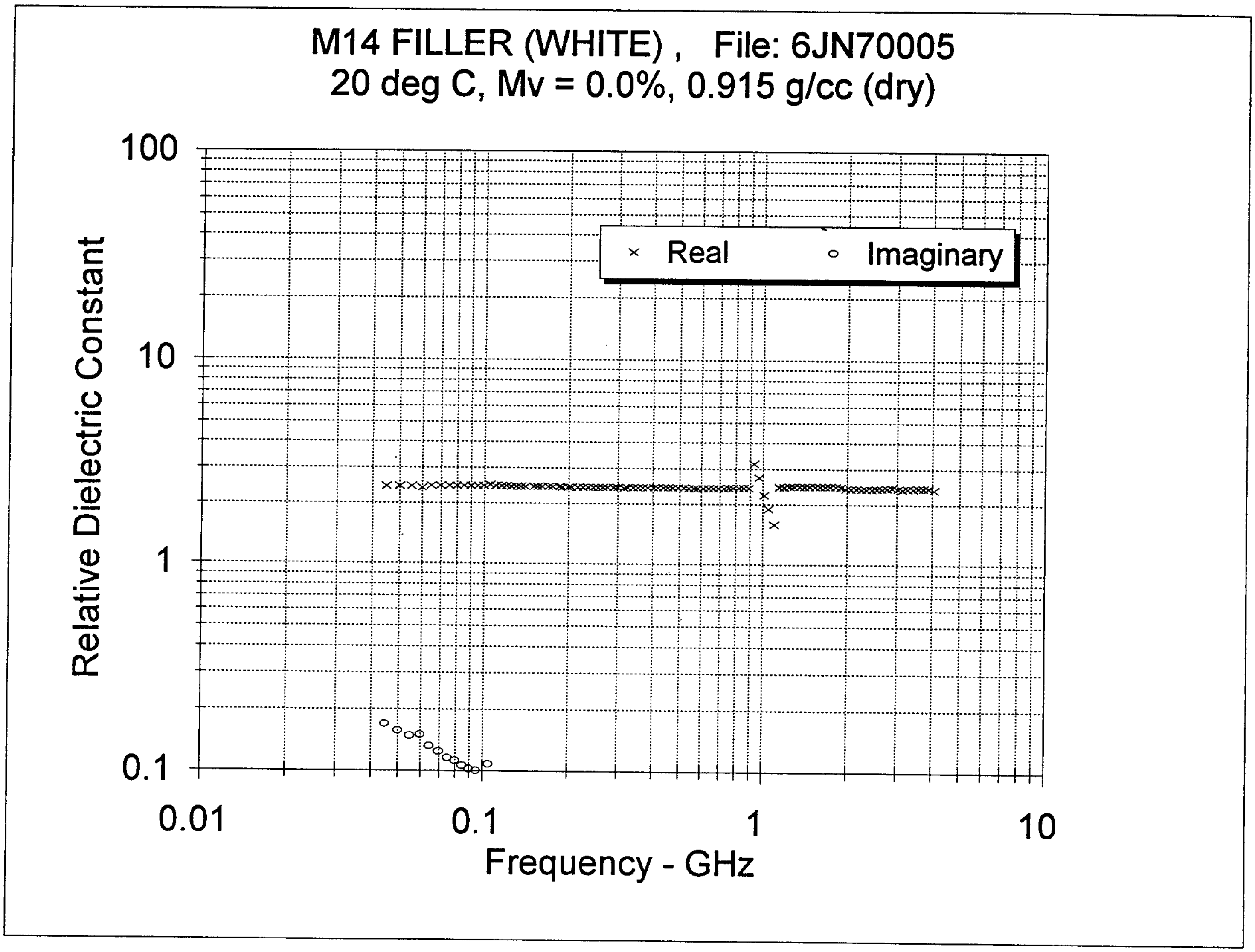

M19 FILLER (RED) , File: 23AG61043
20 deg C, Mv = 0.0%, 1.660 g/cc (dry)
Attenuation
Phase Velocity
Attenuation - dB/m
Normalized Phase Velocity
Frequency - GHz
100
10
1
0.01
0.1
1
10
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

6JN70005
M14 Filler (White)
9.7
3
0
20
0.915

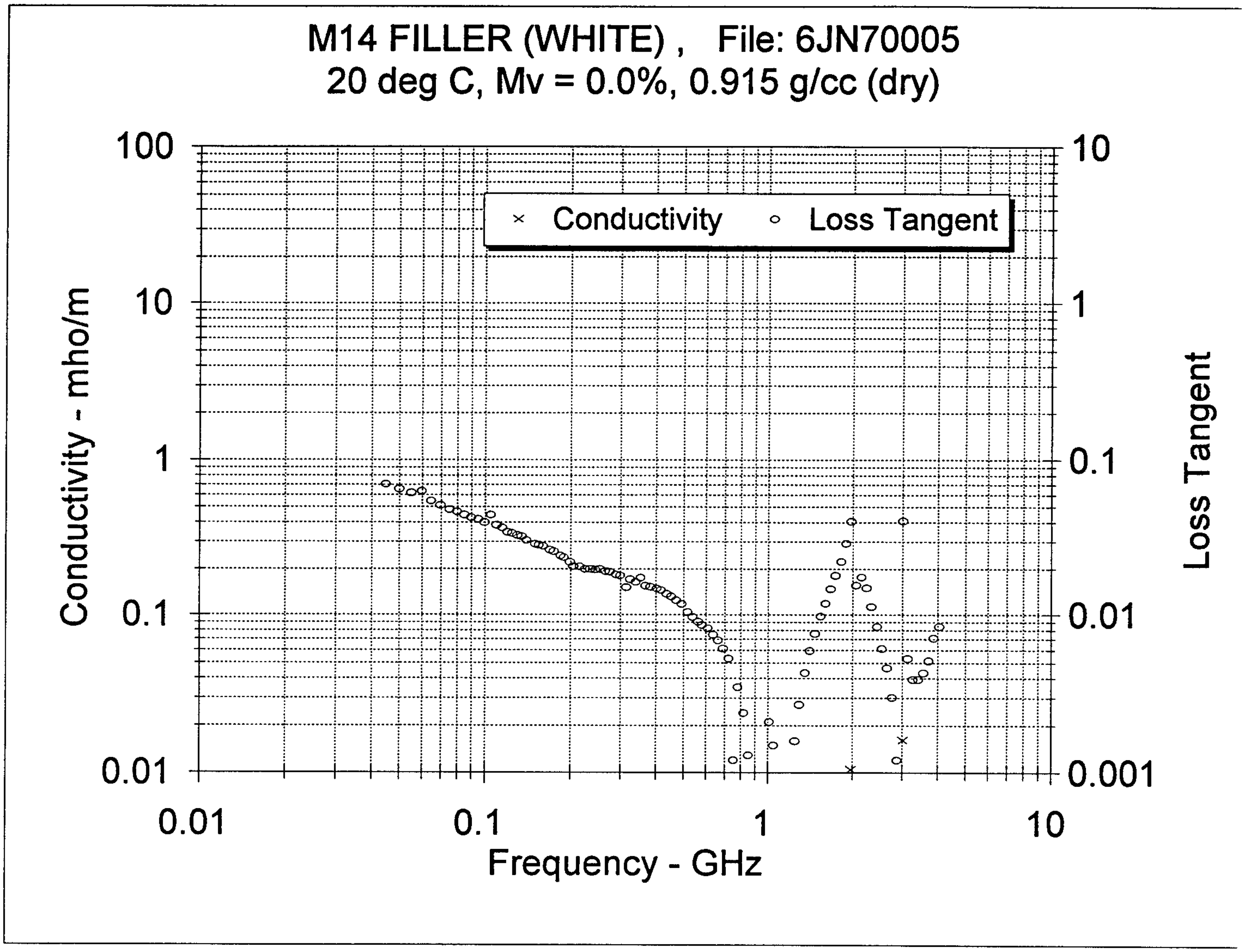
M14 FILLER (WHITE) , File: 6JN70005
20 deg C, Mv = 0.0%, 0.915 g/cc (dry)

Freq GHz	Re(eps)	Im(eps)	Cond mho/m	Loss Tan	Attn dB/m	Norm Vel
0.045	2.41	0.17	0.0004	0.07	0.44	0.64
0.050	2.41	0.16	0.0004	0.07	0.46	0.64
0.055	2.41	0.15	0.0005	0.06	0.48	0.64
0.060	2.37	0.15	0.0005	0.06	0.53	0.65
0.065	2.42	0.13	0.0005	0.05	0.50	0.64
0.070	2.42	0.12	0.0005	0.05	0.51	0.64
0.075	2.42	0.12	0.0005	0.05	0.51	0.64
0.080	2.42	0.11	0.0005	0.05	0.53	0.64
0.085	2.41	0.11	0.0005	0.04	0.53	0.64
0.090	2.42	0.10	0.0005	0.04	0.54	0.64
0.095	2.42	0.10	0.0005	0.04	0.56	0.64
0.100	2.42	0.10	0.0005	0.04	0.56	0.64
0.105	2.44	0.11	0.0006	0.04	0.66	0.64
0.110	2.42	0.09	0.0006	0.04	0.59	0.64
0.115	2.42	0.09	0.0006	0.04	0.59	0.64
0.120	2.41	0.08	0.0006	0.03	0.58	0.64
0.125	2.41	0.08	0.0006	0.03	0.60	0.64
0.130	2.41	0.08	0.0006	0.03	0.60	0.64
0.135	2.41	0.08	0.0006	0.03	0.62	0.64
0.140	2.41	0.07	0.0006	0.03	0.60	0.64
0.150	2.41	0.07	0.0006	0.03	0.61	0.64
0.155	2.41	0.07	0.0006	0.03	0.62	0.64
0.160	2.41	0.07	0.0006	0.03	0.63	0.64
0.170	2.41	0.06	0.0006	0.03	0.63	0.64
0.175	2.40	0.06	0.0006	0.03	0.64	0.64
0.185	2.40	0.06	0.0006	0.02	0.63	0.65
0.190	2.40	0.06	0.0006	0.02	0.63	0.65
0.200	2.40	0.05	0.0006	0.02	0.62	0.65
0.205	2.40	0.05	0.0006	0.02	0.59	0.65
0.215	2.40	0.05	0.0006	0.02	0.62	0.65
0.225	2.40	0.05	0.0006	0.02	0.63	0.65
0.235	2.40	0.05	0.0006	0.02	0.65	0.65
0.245	2.40	0.05	0.0006	0.02	0.68	0.65
0.255	2.40	0.05	0.0007	0.02	0.71	0.65
0.265	2.40	0.05	0.0007	0.02	0.72	0.65
0.275	2.39	0.05	0.0007	0.02	0.74	0.65
0.290	2.39	0.04	0.0007	0.02	0.75	0.65
0.300	2.39	0.04	0.0007	0.02	0.76	0.65
0.315	2.38	0.04	0.0006	0.02	0.66	0.65
0.325	2.39	0.04	0.0007	0.02	0.78	0.65
0.340	2.39	0.04	0.0007	0.02	0.79	0.65
0.355	2.40	0.04	0.0008	0.02	0.87	0.65
0.370	2.39	0.04	0.0008	0.02	0.81	0.65
0.385	2.39	0.04	0.0008	0.02	0.82	0.65
0.405	2.39	0.04	0.0008	0.01	0.84	0.65

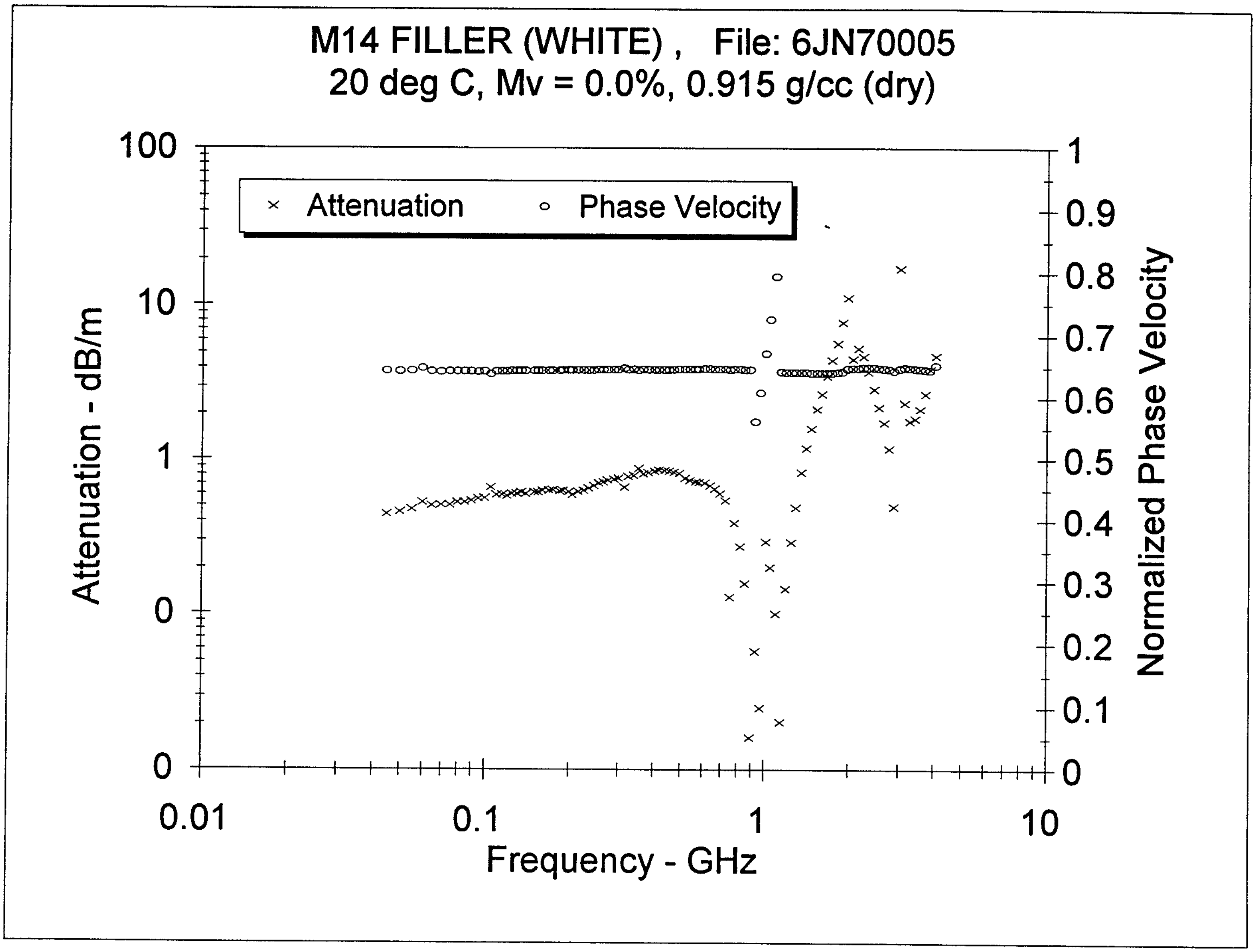
0.420	2.39	0.03	0.0008	0.01	0.86	0.65
0.440	2.39	0.03	0.0008	0.01	0.85	0.65
0.455	2.39	0.03	0.0008	0.01	0.84	0.65
0.475	2.39	0.03	0.0008	0.01	0.83	0.65
0.495	2.39	0.03	0.0008	0.01	0.82	0.65
0.520	2.39	0.02	0.0007	0.01	0.76	0.65
0.540	2.39	0.02	0.0007	0.01	0.74	0.65
0.565	2.39	0.02	0.0007	0.01	0.71	0.65
0.585	2.39	0.02	0.0007	0.01	0.71	0.65
0.610	2.39	0.02	0.0007	0.01	0.71	0.65
0.640	2.39	0.02	0.0006	0.01	0.68	0.65
0.665	2.39	0.02	0.0006	0.01	0.65	0.65
0.695	2.39	0.01	0.0006	0.01	0.60	0.65
0.725	2.39	0.01	0.0005	0.01	0.54	0.65
0.755	2.39	0.00	0.0001	0.00	0.13	0.65
0.785	2.39	0.01	0.0004	0.00	0.39	0.65
0.820	2.39	0.01	0.0003	0.00	0.27	0.65
0.855	2.39	0.00	0.0001	0.00	0.16	0.65
0.895	2.39	0.00	0.0001	0.00	0.02	0.65
0.930	3.16	0.00	0.0001	0.00	0.06	0.56
0.970	2.70	0.00	0.0001	0.00	0.03	0.61
1.015	2.22	0.00	0.0003	0.00	0.29	0.67
1.055	1.89	0.00	0.0002	0.00	0.20	0.73
1.100	1.58	0.00	0.0001	0.00	0.10	0.80
1.150	2.42	0.00	0.0001	0.00	0.02	0.64
1.195	2.43	0.00	0.0001	0.00	0.14	0.64
1.250	2.43	0.00	0.0003	0.00	0.29	0.64
1.300	2.43	0.01	0.0005	0.00	0.49	0.64
1.360	2.43	0.01	0.0008	0.00	0.83	0.64
1.415	2.43	0.01	0.0011	0.01	1.18	0.64
1.475	2.43	0.02	0.0015	0.01	1.60	0.64
1.540	2.43	0.02	0.0020	0.01	2.13	0.64
1.605	2.43	0.03	0.0026	0.01	2.69	0.64
1.675	2.43	0.04	0.0033	0.01	3.50	0.64
1.745	2.43	0.04	0.0042	0.02	4.46	0.64
1.820	2.43	0.05	0.0055	0.02	5.73	0.64
1.900	2.42	0.07	0.0074	0.03	7.80	0.64
1.980	2.38	0.10	0.0105	0.04	11.15	0.65
2.065	2.38	0.04	0.0043	0.02	4.52	0.65
2.155	2.38	0.04	0.0050	0.02	5.28	0.65
2.250	2.37	0.04	0.0044	0.01	4.69	0.65
2.345	2.37	0.03	0.0035	0.01	3.72	0.65
2.445	2.37	0.02	0.0027	0.01	2.87	0.65
2.550	2.38	0.01	0.0021	0.01	2.20	0.65
2.660	2.38	0.01	0.0016	0.00	1.73	0.65
2.775	2.39	0.01	0.0011	0.00	1.18	0.65
2.890	2.41	0.00	0.0005	0.00	0.50	0.64
3.015	2.38	0.10	0.0162	0.04	17.14	0.65
3.145	2.37	0.01	0.0022	0.01	2.34	0.65
3.280	2.38	0.01	0.0017	0.00	1.78	0.65
3.420	2.39	0.01	0.0018	0.00	1.85	0.65
3.570	2.39	0.01	0.0020	0.00	2.14	0.65
3.720	2.39	0.01	0.0025	0.01	2.69	0.65
3.880	2.40	0.02	0.0037	0.01	3.86	0.65
4.045	2.35	0.02	0.0044	0.01	4.73	0.65



M14 FILLER (WHITE) , File: 6JN70005
20 deg C, Mv = 0.0%, 0.915 g/cc (dry)
Real
Imaginary
100
10
1
0.1
Relative Dielectric Constant
0.01
0.1
1
10
Frequency - GHz



M14 FILLER (WHITE) , File: 6JN70005
20 deg C, Mv = 0.0%, 0.915 g/cc (dry)
Conductivity
Loss Tangent
Conductivity - mho/m
Loss Tangent
Frequency - GHz
100
10
1
0.1
0.01
0.001
0.01
0.1
1
10



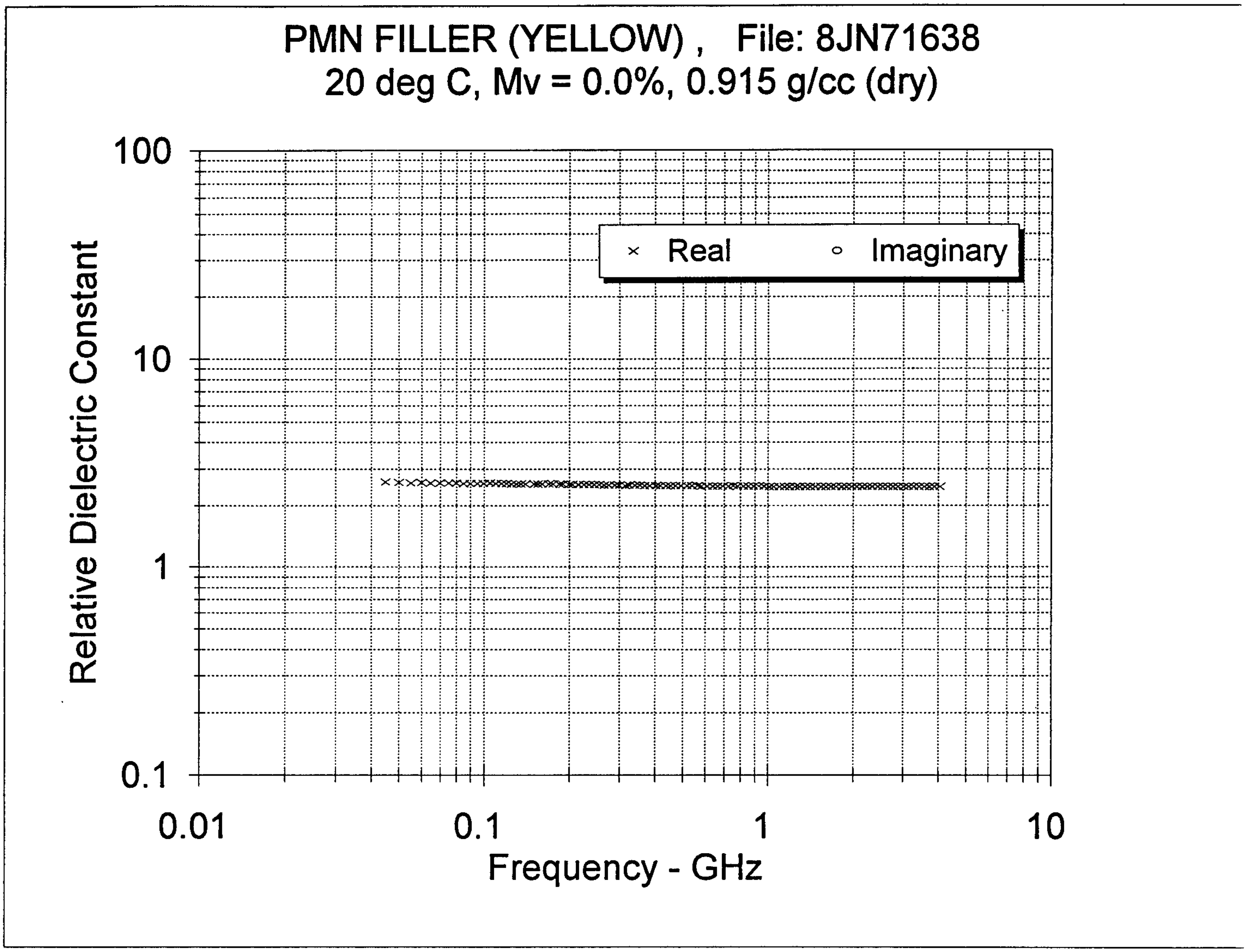
M14 FILLER (WHITE) , File: 6JN70005
20 deg C, Mv = 0.0%, 0.915 g/cc (dry)
Attenuation
Phase Velocity
Attenuation - dB/m
Normalized Phase Velocity
Frequency - GHz
100
10
1
0
0
0.01
0.1
1
10
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

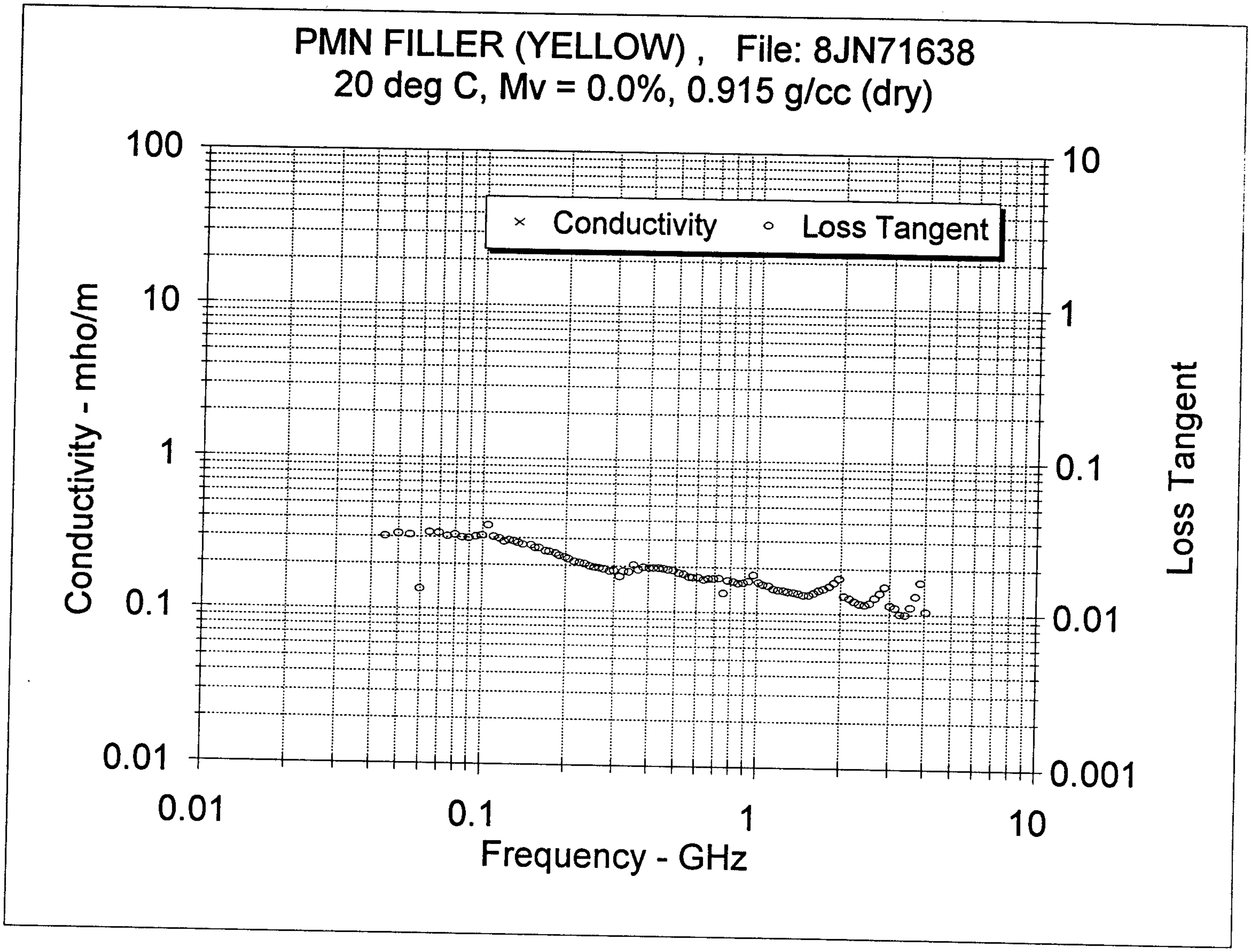
8JN71638
PMN Filler (Yellow)
9.7
3
0
20
0.915

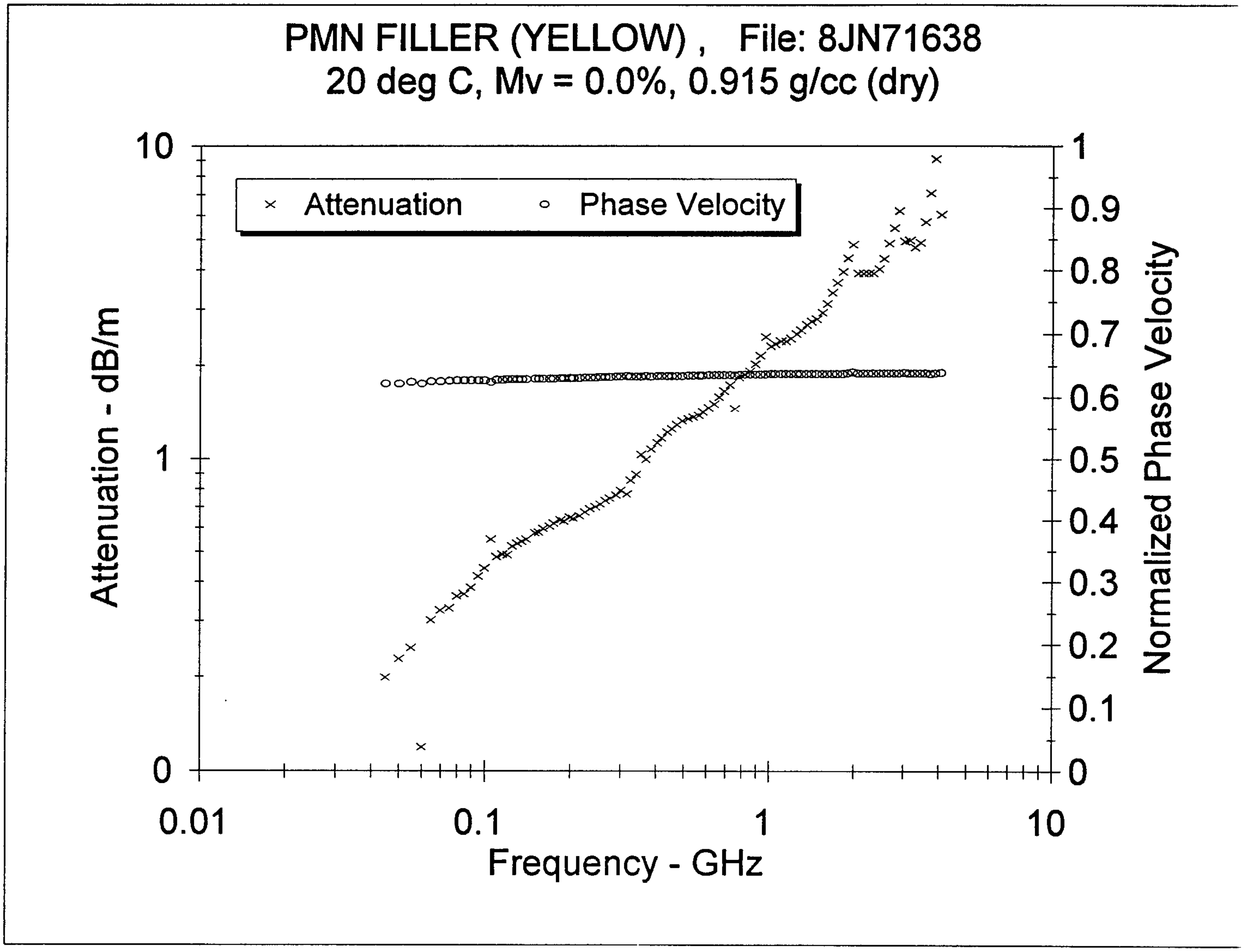
PMN FILLER (YELLOW) , File: 8JN71638
20 deg C, Mv = 0.0%, 0.915 g/cc (dry)

Freq GHz	Re(eps)	Im(eps)	Cond mho/m	Loss Tan	Attn dB/m	Norm Vel
0.045	2.59	0.08	0.0002	0.03	0.20	0.62
0.050	2.58	0.08	0.0002	0.03	0.23	0.62
0.055	2.57	0.08	0.0002	0.03	0.25	0.62
0.060	2.58	0.04	0.0001	0.01	0.12	0.62
0.065	2.56	0.08	0.0003	0.03	0.30	0.63
0.070	2.56	0.08	0.0003	0.03	0.32	0.63
0.075	2.55	0.08	0.0003	0.03	0.33	0.63
0.080	2.55	0.08	0.0004	0.03	0.36	0.63
0.085	2.54	0.08	0.0004	0.03	0.37	0.63
0.090	2.54	0.07	0.0004	0.03	0.38	0.63
0.095	2.54	0.08	0.0004	0.03	0.42	0.63
0.100	2.54	0.08	0.0004	0.03	0.44	0.63
0.105	2.56	0.09	0.0005	0.04	0.55	0.62
0.110	2.53	0.08	0.0005	0.03	0.48	0.63
0.115	2.53	0.07	0.0005	0.03	0.49	0.63
0.120	2.53	0.07	0.0005	0.03	0.49	0.63
0.125	2.53	0.07	0.0005	0.03	0.52	0.63
0.130	2.53	0.07	0.0005	0.03	0.53	0.63
0.135	2.53	0.07	0.0005	0.03	0.54	0.63
0.140	2.52	0.07	0.0005	0.03	0.55	0.63
0.150	2.52	0.07	0.0006	0.03	0.58	0.63
0.155	2.52	0.07	0.0006	0.03	0.58	0.63
0.160	2.52	0.07	0.0006	0.03	0.60	0.63
0.170	2.52	0.06	0.0006	0.02	0.61	0.63
0.175	2.52	0.06	0.0006	0.02	0.62	0.63
0.185	2.52	0.06	0.0006	0.02	0.63	0.63
0.190	2.52	0.06	0.0006	0.02	0.63	0.63
0.200	2.51	0.06	0.0006	0.02	0.65	0.63
0.205	2.51	0.05	0.0006	0.02	0.64	0.63
0.215	2.51	0.05	0.0006	0.02	0.65	0.63
0.225	2.51	0.05	0.0007	0.02	0.67	0.63
0.235	2.51	0.05	0.0007	0.02	0.69	0.63
0.245	2.51	0.05	0.0007	0.02	0.70	0.63
0.255	2.51	0.05	0.0007	0.02	0.72	0.63
0.265	2.50	0.05	0.0007	0.02	0.74	0.63
0.275	2.50	0.05	0.0007	0.02	0.75	0.63
0.290	2.50	0.05	0.0007	0.02	0.77	0.63
0.300	2.50	0.05	0.0008	0.02	0.80	0.63
0.315	2.48	0.04	0.0007	0.02	0.77	0.63
0.325	2.49	0.05	0.0008	0.02	0.86	0.63
0.340	2.49	0.05	0.0009	0.02	0.89	0.63
0.355	2.50	0.05	0.0010	0.02	1.04	0.63
0.370	2.49	0.05	0.0010	0.02	1.00	0.63
0.385	2.49	0.05	0.0010	0.02	1.08	0.63
0.405	2.49	0.05	0.0011	0.02	1.13	0.63

0.420	2.49	0.05	0.0011	0.02	1.17	0.63
0.440	2.49	0.05	0.0012	0.02	1.23	0.63
0.455	2.49	0.05	0.0012	0.02	1.26	0.63
0.475	2.49	0.05	0.0013	0.02	1.30	0.63
0.495	2.48	0.05	0.0013	0.02	1.33	0.63
0.520	2.48	0.05	0.0013	0.02	1.36	0.63
0.540	2.48	0.04	0.0013	0.02	1.37	0.63
0.565	2.48	0.04	0.0013	0.02	1.39	0.64
0.585	2.48	0.04	0.0014	0.02	1.43	0.64
0.610	2.48	0.04	0.0014	0.02	1.47	0.64
0.640	2.47	0.04	0.0015	0.02	1.51	0.64
0.665	2.48	0.04	0.0015	0.02	1.59	0.64
0.695	2.47	0.04	0.0016	0.02	1.67	0.64
0.725	2.47	0.04	0.0017	0.02	1.74	0.64
0.755	2.48	0.03	0.0014	0.01	1.46	0.64
0.785	2.47	0.04	0.0018	0.02	1.83	0.64
0.820	2.47	0.04	0.0018	0.02	1.88	0.64
0.855	2.47	0.04	0.0018	0.02	1.92	0.64
0.895	2.47	0.04	0.0019	0.02	2.02	0.64
0.930	2.47	0.04	0.0021	0.02	2.15	0.64
0.970	2.47	0.04	0.0024	0.02	2.46	0.64
1.015	2.46	0.04	0.0022	0.02	2.30	0.64
1.055	2.46	0.04	0.0022	0.02	2.34	0.64
1.100	2.46	0.04	0.0023	0.02	2.38	0.64
1.150	2.46	0.04	0.0023	0.01	2.38	0.64
1.195	2.46	0.04	0.0023	0.01	2.43	0.64
1.250	2.46	0.03	0.0024	0.01	2.51	0.64
1.300	2.46	0.03	0.0025	0.01	2.57	0.64
1.360	2.46	0.03	0.0026	0.01	2.68	0.64
1.415	2.46	0.03	0.0026	0.01	2.75	0.64
1.475	2.46	0.03	0.0027	0.01	2.80	0.64
1.540	2.46	0.03	0.0028	0.01	2.93	0.64
1.605	2.46	0.03	0.0030	0.01	3.13	0.64
1.675	2.46	0.03	0.0032	0.01	3.39	0.64
1.745	2.46	0.04	0.0035	0.01	3.65	0.64
1.820	2.46	0.04	0.0038	0.02	3.95	0.64
1.900	2.46	0.04	0.0042	0.02	4.36	0.64
1.980	2.44	0.04	0.0046	0.02	4.83	0.64
2.065	2.45	0.03	0.0037	0.01	3.89	0.64
2.155	2.45	0.03	0.0037	0.01	3.89	0.64
2.250	2.45	0.03	0.0037	0.01	3.89	0.64
2.345	2.46	0.03	0.0037	0.01	3.91	0.64
2.445	2.46	0.03	0.0039	0.01	4.04	0.64
2.550	2.46	0.03	0.0042	0.01	4.34	0.64
2.660	2.46	0.03	0.0047	0.01	4.86	0.64
2.775	2.46	0.03	0.0052	0.01	5.46	0.64
2.890	2.46	0.04	0.0060	0.02	6.22	0.64
3.015	2.45	0.03	0.0047	0.01	4.95	0.64
3.145	2.45	0.03	0.0048	0.01	4.98	0.64
3.280	2.45	0.02	0.0045	0.01	4.73	0.64
3.420	2.46	0.02	0.0047	0.01	4.90	0.64
3.570	2.46	0.03	0.0055	0.01	5.69	0.64
3.720	2.46	0.03	0.0068	0.01	7.06	0.64
3.880	2.46	0.04	0.0087	0.02	9.08	0.64
4.045	2.45	0.03	0.0058	0.01	6.03	0.64


PMN FILLER (YELLOW) , File: 8JN71638
20 deg C, Mv = 0.0%, 0.915 g/cc (dry)
Real
Imaginary
100
10
1
0.1
0.01
0.1
1
10
Relative Dielectric Constant
Frequency - GHz


PMN FILLER (YELLOW) , File: 8JN71638
20 deg C, Mv = 0.0%, 0.915 g/cc (dry)
Conductivity
Loss Tangent
Conductivity - mho/m
Loss Tangent
Frequency - GHz
100
10
1
0.1
0.01
0.001

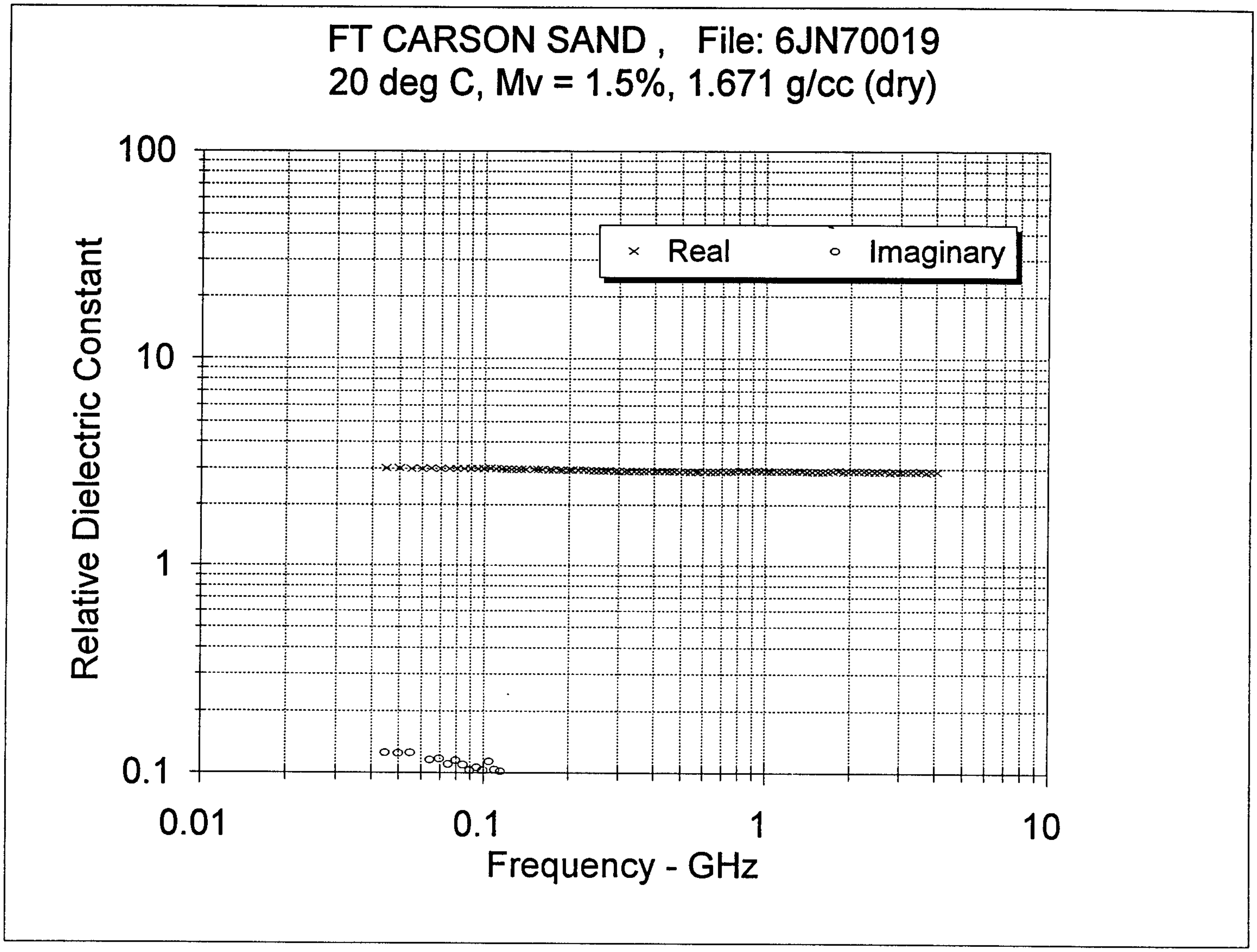

PMN FILLER (YELLOW) , File: 8JN71638
20 deg C, Mv = 0.0%, 0.915 g/cc (dry)
Attenuation
Phase Velocity
Attenuation - dB/m
Normalized Phase Velocity
Frequency - GHz
10
1
0
0.01
0.1
1
10
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1

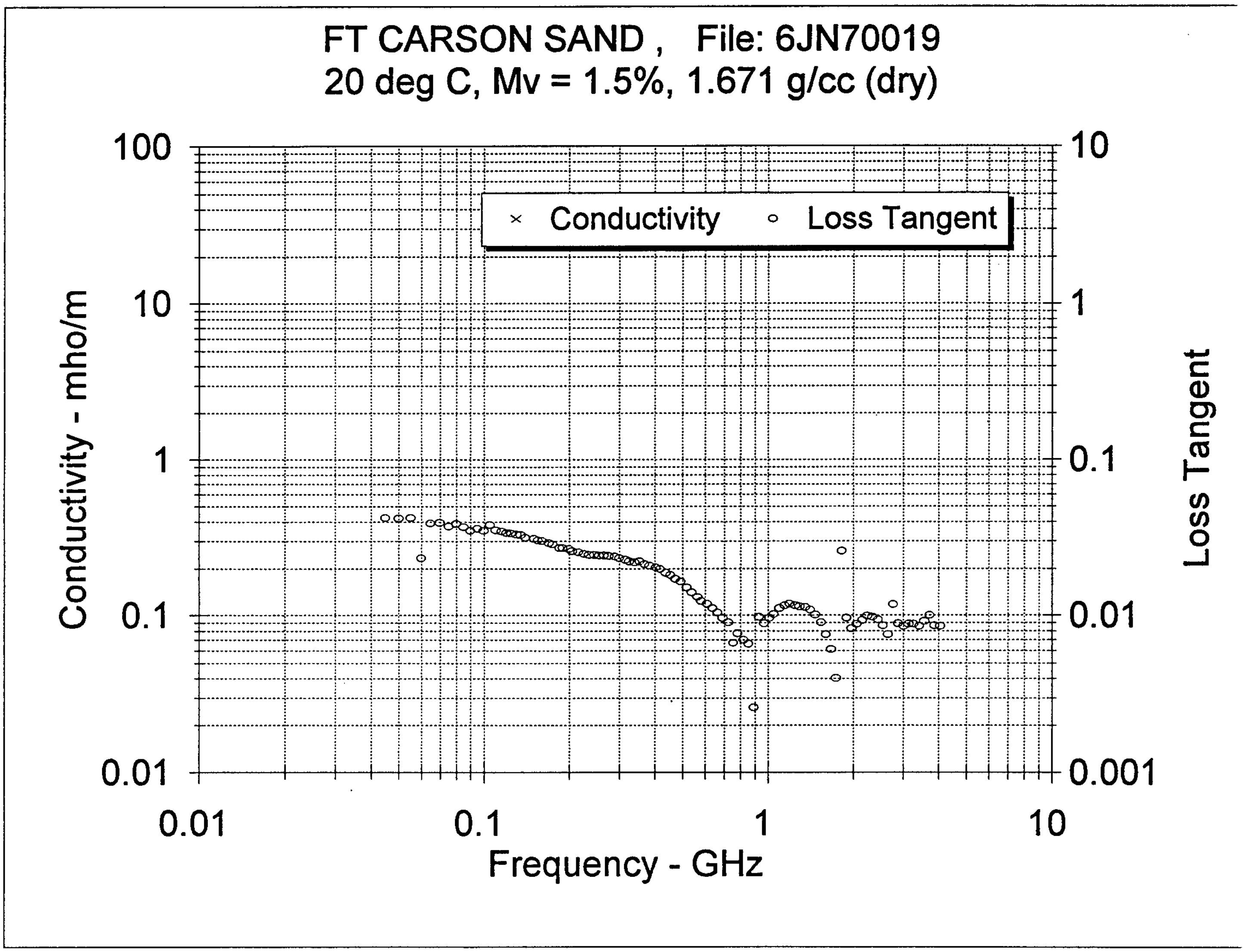
6JN70019
Ft Carson Sand
9.7
2
1.52
20
1.671

FT CARSON SAND , File: 6JN70019
20 deg C, Mv = 1.5%, 1.671 g/cc (dry)

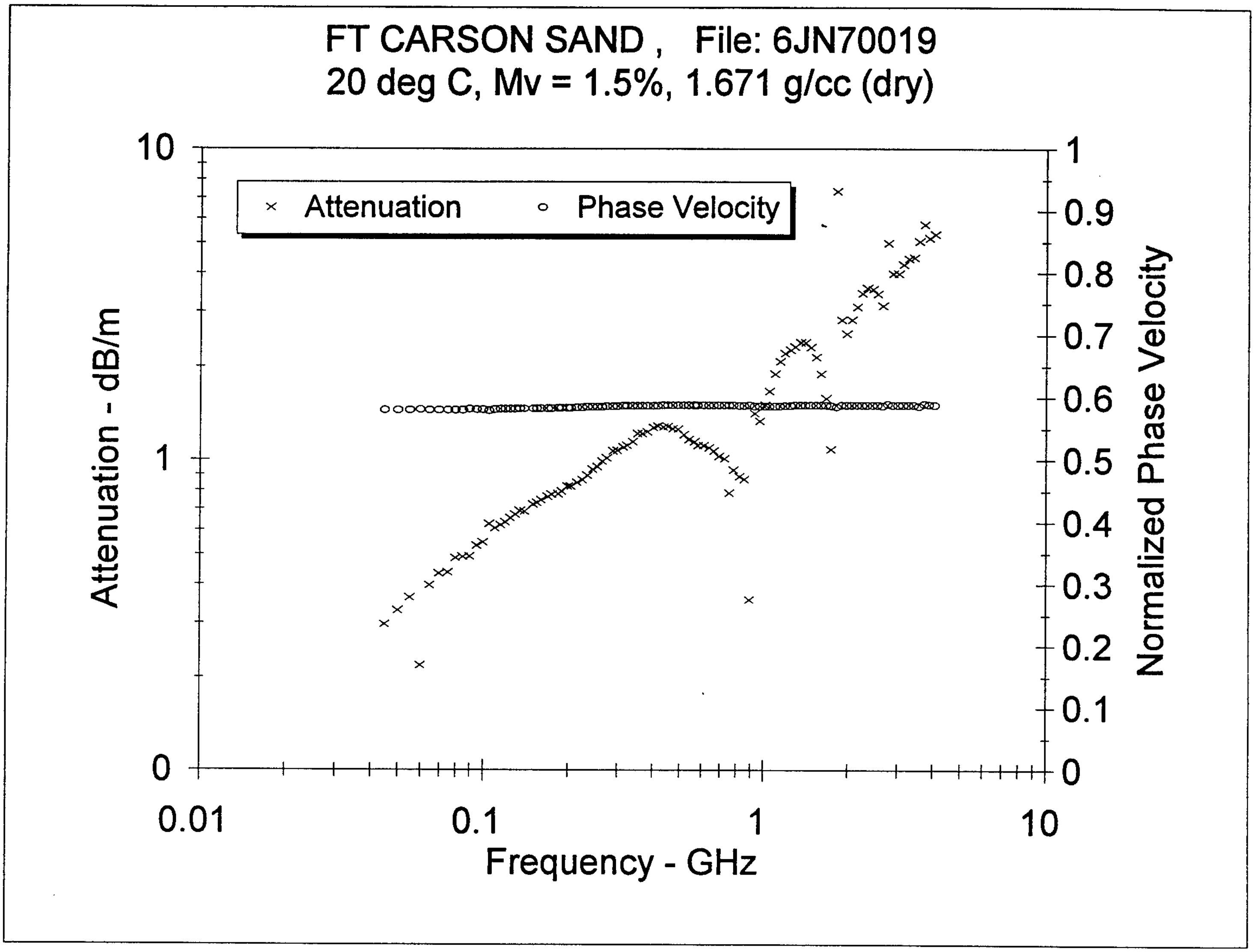
Freq GHz	Re(eps)	Im(eps)	Cond mho/m	Loss Tan	Attn dB/m	Norm Vel
0.045	2.97	0.13	0.0003	0.04	0.30	0.58
0.050	2.97	0.12	0.0003	0.04	0.33	0.58
0.055	2.97	0.13	0.0004	0.04	0.36	0.58
0.060	2.96	0.07	0.0002	0.02	0.22	0.58
0.065	2.97	0.12	0.0004	0.04	0.40	0.58
0.070	2.97	0.12	0.0005	0.04	0.43	0.58
0.075	2.97	0.11	0.0005	0.04	0.44	0.58
0.080	2.97	0.12	0.0005	0.04	0.49	0.58
0.085	2.97	0.11	0.0005	0.04	0.49	0.58
0.090	2.96	0.10	0.0005	0.04	0.49	0.58
0.095	2.97	0.11	0.0006	0.04	0.54	0.58
0.100	2.96	0.10	0.0006	0.04	0.55	0.58
0.105	2.98	0.11	0.0007	0.04	0.63	0.58
0.110	2.96	0.10	0.0006	0.04	0.61	0.58
0.115	2.96	0.10	0.0007	0.03	0.62	0.58
0.120	2.95	0.10	0.0007	0.03	0.63	0.58
0.125	2.95	0.10	0.0007	0.03	0.65	0.58
0.130	2.95	0.10	0.0007	0.03	0.67	0.58
0.135	2.95	0.10	0.0007	0.03	0.69	0.58
0.140	2.95	0.09	0.0007	0.03	0.69	0.58
0.150	2.95	0.09	0.0008	0.03	0.72	0.58
0.155	2.94	0.09	0.0008	0.03	0.73	0.58
0.160	2.94	0.09	0.0008	0.03	0.75	0.58
0.170	2.94	0.09	0.0008	0.03	0.77	0.58
0.175	2.94	0.08	0.0008	0.03	0.78	0.58
0.185	2.93	0.08	0.0008	0.03	0.78	0.58
0.190	2.93	0.08	0.0008	0.03	0.80	0.58
0.200	2.93	0.08	0.0009	0.03	0.83	0.58
0.205	2.93	0.08	0.0009	0.03	0.83	0.58
0.215	2.93	0.07	0.0009	0.03	0.85	0.58
0.225	2.93	0.07	0.0009	0.02	0.87	0.58
0.235	2.92	0.07	0.0009	0.02	0.90	0.59
0.245	2.92	0.07	0.0010	0.02	0.93	0.59
0.255	2.92	0.07	0.0010	0.02	0.95	0.59
0.265	2.91	0.07	0.0010	0.02	0.99	0.59
0.275	2.91	0.07	0.0011	0.02	1.02	0.59
0.290	2.91	0.07	0.0011	0.02	1.07	0.59
0.300	2.91	0.07	0.0011	0.02	1.08	0.59
0.315	2.91	0.07	0.0011	0.02	1.10	0.59
0.325	2.90	0.06	0.0012	0.02	1.12	0.59
0.340	2.90	0.06	0.0012	0.02	1.14	0.59
0.355	2.91	0.06	0.0013	0.02	1.22	0.59
0.370	2.90	0.06	0.0013	0.02	1.22	0.59
0.385	2.90	0.06	0.0013	0.02	1.23	0.59
0.405	2.90	0.06	0.0013	0.02	1.27	0.59

0.420	2.90	0.06	0.0013	0.02	1.29	0.59
0.440	2.90	0.05	0.0013	0.02	1.28	0.59
0.455	2.90	0.05	0.0013	0.02	1.29	0.59
0.475	2.90	0.05	0.0013	0.02	1.26	0.59
0.495	2.89	0.05	0.0013	0.02	1.26	0.59
0.520	2.89	0.04	0.0013	0.02	1.21	0.59
0.540	2.89	0.04	0.0012	0.01	1.17	0.59
0.565	2.89	0.04	0.0012	0.01	1.14	0.59
0.585	2.89	0.04	0.0012	0.01	1.12	0.59
0.610	2.89	0.03	0.0012	0.01	1.12	0.59
0.640	2.89	0.03	0.0011	0.01	1.09	0.59
0.665	2.89	0.03	0.0011	0.01	1.07	0.59
0.695	2.89	0.03	0.0011	0.01	1.03	0.59
0.725	2.89	0.03	0.0011	0.01	1.01	0.59
0.755	2.90	0.02	0.0008	0.01	0.79	0.59
0.785	2.90	0.02	0.0010	0.01	0.93	0.59
0.820	2.90	0.02	0.0009	0.01	0.89	0.59
0.855	2.90	0.02	0.0009	0.01	0.87	0.59
0.895	2.90	0.01	0.0004	0.00	0.36	0.59
0.930	2.91	0.03	0.0015	0.01	1.41	0.59
0.970	2.91	0.03	0.0014	0.01	1.33	0.59
1.015	2.91	0.03	0.0016	0.01	1.50	0.59
1.055	2.91	0.03	0.0017	0.01	1.67	0.59
1.100	2.91	0.03	0.0020	0.01	1.89	0.59
1.150	2.91	0.03	0.0022	0.01	2.07	0.59
1.195	2.91	0.03	0.0023	0.01	2.20	0.59
1.250	2.90	0.03	0.0023	0.01	2.25	0.59
1.300	2.90	0.03	0.0024	0.01	2.30	0.59
1.360	2.90	0.03	0.0025	0.01	2.39	0.59
1.415	2.89	0.03	0.0025	0.01	2.39	0.59
1.475	2.89	0.03	0.0024	0.01	2.30	0.59
1.540	2.89	0.03	0.0022	0.01	2.14	0.59
1.605	2.89	0.02	0.0020	0.01	1.89	0.59
1.675	2.89	0.02	0.0016	0.01	1.58	0.59
1.745	2.90	0.01	0.0011	0.00	1.08	0.59
1.820	2.92	0.08	0.0077	0.03	7.33	0.59
1.900	2.89	0.03	0.0029	0.01	2.83	0.59
1.980	2.89	0.02	0.0026	0.01	2.54	0.59
2.065	2.90	0.03	0.0029	0.01	2.82	0.59
2.155	2.90	0.03	0.0032	0.01	3.11	0.59
2.250	2.90	0.03	0.0036	0.01	3.44	0.59
2.345	2.89	0.03	0.0037	0.01	3.57	0.59
2.445	2.89	0.03	0.0037	0.01	3.55	0.59
2.550	2.89	0.03	0.0035	0.01	3.41	0.59
2.660	2.90	0.02	0.0033	0.01	3.13	0.59
2.775	2.88	0.03	0.0052	0.01	5.00	0.59
2.890	2.89	0.03	0.0041	0.01	3.98	0.59
3.015	2.89	0.02	0.0041	0.01	3.98	0.59
3.145	2.89	0.03	0.0044	0.01	4.26	0.59
3.280	2.89	0.03	0.0046	0.01	4.46	0.59
3.420	2.89	0.02	0.0047	0.01	4.49	0.59
3.570	2.91	0.03	0.0053	0.01	5.07	0.59
3.720	2.87	0.03	0.0059	0.01	5.72	0.59
3.880	2.88	0.02	0.0054	0.01	5.18	0.59
4.045	2.89	0.02	0.0055	0.01	5.31	0.59


FT CARSON SAND , File: 6JN70019
20 deg C, Mv = 1.5%, 1.671 g/cc (dry)
Relative Dielectric Constant
100
10
1
0.1
Real
Imaginary
0.01
0.1
1
10
Frequency - GHz



FT CARSON SAND , File: 6JN70019
20 deg C, Mv = 1.5%, 1.671 g/cc (dry)
Conductivity
Loss Tangent
Conductivity - mho/m
Loss Tangent
Frequency - GHz
100
10
1
0.1
0.01
0.01
0.1
1
10
10
1
0.1
0.01
0.001

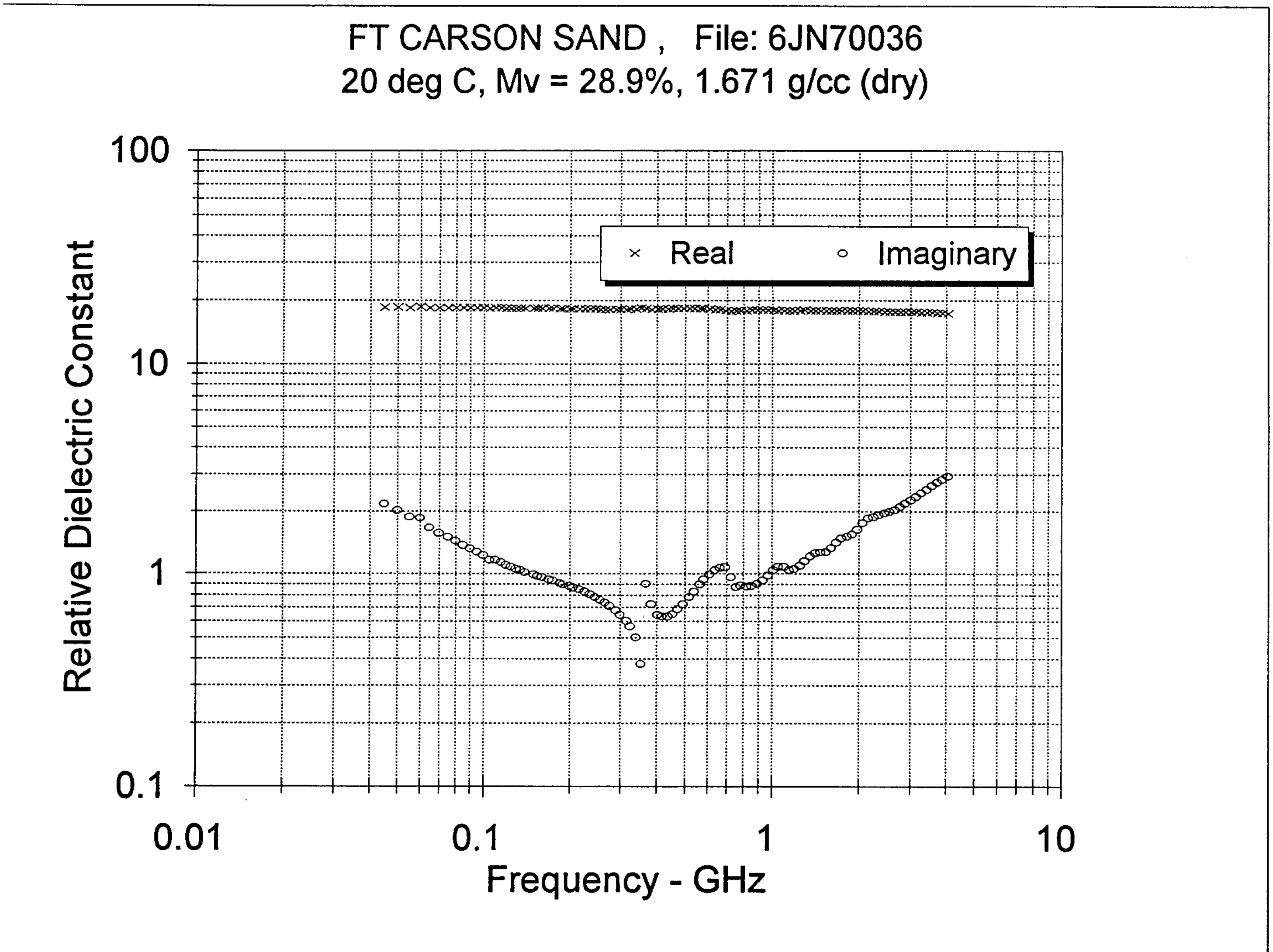

FT CARSON SAND , File: 6JN70019
20 deg C, Mv = 1.5%, 1.671 g/cc (dry)
Attenuation
Phase Velocity
Attenuation - dB/m
Normalized Phase Velocity
Frequency - GHz
10
1
0
0.01
0.1
1
10
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1

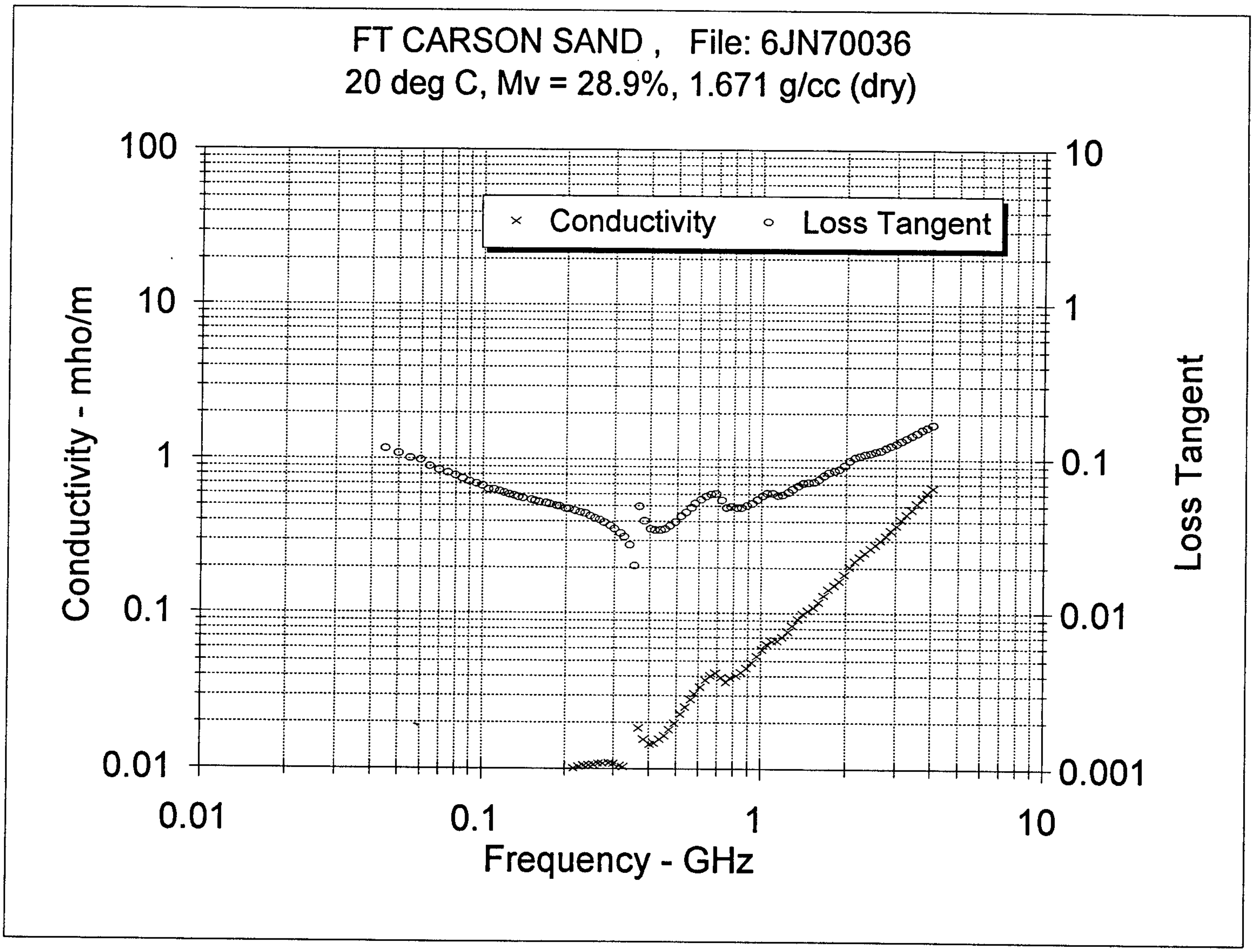
6JN70036
Ft Carson Sand
9.7
2
28.85
20
1.671

FT CARSON SAND , File: 6JN70036
20 deg C, Mv = 28.9%, 1.671 g/cc (dry)

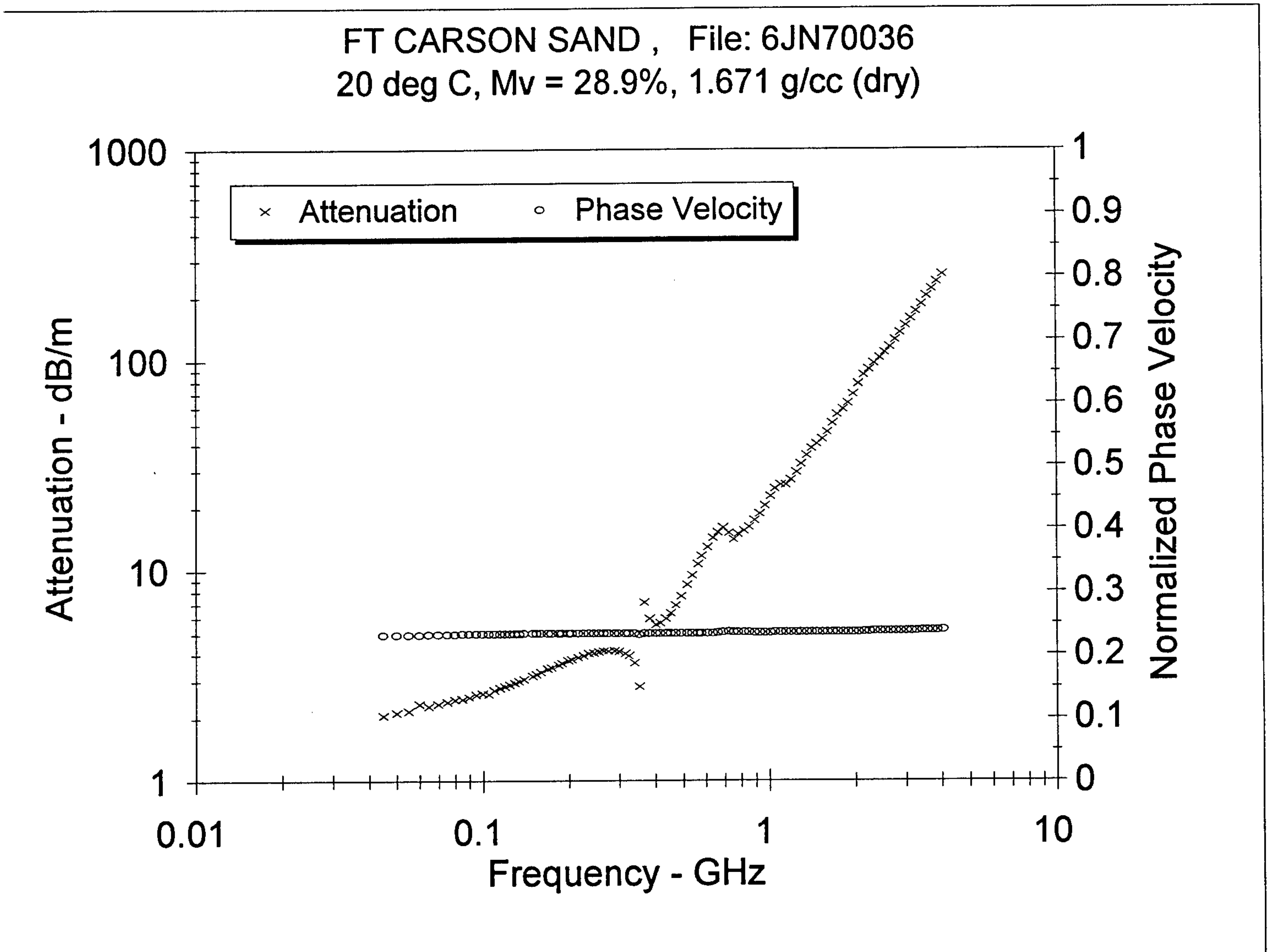
Freq GHz	Re(eps)	Im(eps)	Cond mho/m	Loss Tan	Attn dB/m	Norm Vel
0.045	18.54	2.16	0.0054	0.12	2.05	0.23
0.050	18.53	2.00	0.0056	0.11	2.12	0.23
0.055	18.49	1.86	0.0057	0.10	2.16	0.23
0.060	18.59	1.84	0.0062	0.10	2.33	0.23
0.065	18.45	1.66	0.0060	0.09	2.28	0.23
0.070	18.43	1.57	0.0061	0.09	2.32	0.23
0.075	18.44	1.50	0.0063	0.08	2.38	0.23
0.080	18.40	1.44	0.0064	0.08	2.44	0.23
0.085	18.38	1.37	0.0065	0.07	2.47	0.23
0.090	18.36	1.32	0.0066	0.07	2.51	0.23
0.095	18.36	1.28	0.0067	0.07	2.57	0.23
0.100	18.34	1.23	0.0069	0.07	2.62	0.23
0.105	18.28	1.16	0.0068	0.06	2.60	0.23
0.110	18.33	1.16	0.0071	0.06	2.72	0.23
0.115	18.31	1.14	0.0073	0.06	2.78	0.23
0.120	18.29	1.11	0.0074	0.06	2.82	0.23
0.125	18.29	1.08	0.0075	0.06	2.88	0.23
0.130	18.28	1.06	0.0077	0.06	2.93	0.23
0.135	18.27	1.04	0.0078	0.06	2.99	0.23
0.140	18.26	1.02	0.0080	0.06	3.05	0.23
0.150	18.25	0.99	0.0083	0.05	3.17	0.23
0.155	18.24	0.98	0.0084	0.05	3.23	0.23
0.160	18.23	0.97	0.0086	0.05	3.30	0.23
0.170	18.22	0.94	0.0089	0.05	3.42	0.23
0.175	18.21	0.93	0.0091	0.05	3.48	0.23
0.185	18.19	0.91	0.0094	0.05	3.58	0.23
0.190	18.19	0.90	0.0095	0.05	3.64	0.23
0.200	18.17	0.88	0.0098	0.05	3.75	0.23
0.205	18.16	0.87	0.0099	0.05	3.79	0.23
0.215	18.15	0.85	0.0101	0.05	3.89	0.23
0.225	18.13	0.82	0.0103	0.05	3.96	0.23
0.235	18.13	0.81	0.0105	0.04	4.05	0.23
0.245	18.11	0.78	0.0106	0.04	4.08	0.23
0.255	18.11	0.76	0.0107	0.04	4.12	0.24
0.265	18.10	0.73	0.0108	0.04	4.16	0.24
0.275	18.09	0.71	0.0108	0.04	4.17	0.24
0.290	18.09	0.67	0.0109	0.04	4.18	0.24
0.300	18.09	0.64	0.0108	0.04	4.14	0.24
0.315	18.10	0.60	0.0105	0.03	4.05	0.24
0.325	18.12	0.57	0.0103	0.03	3.95	0.23
0.340	18.17	0.50	0.0095	0.03	3.66	0.23
0.355	18.43	0.38	0.0074	0.02	2.83	0.23
0.370	18.22	0.90	0.0185	0.05	7.10	0.23
0.385	18.10	0.72	0.0155	0.04	5.95	0.24
0.405	18.13	0.64	0.0145	0.04	5.57	0.23

0.420	18.16	0.63	0.0147	0.03	5.64	0.23
0.440	18.19	0.63	0.0155	0.03	5.95	0.23
0.455	18.22	0.65	0.0164	0.04	6.29	0.23
0.475	18.24	0.68	0.0180	0.04	6.88	0.23
0.495	18.26	0.72	0.0198	0.04	7.60	0.23
0.520	18.27	0.78	0.0226	0.04	8.63	0.23
0.540	18.27	0.83	0.0250	0.05	9.55	0.23
0.565	18.25	0.89	0.0281	0.05	10.76	0.23
0.585	18.23	0.94	0.0307	0.05	11.75	0.23
0.610	18.18	1.00	0.0338	0.05	12.96	0.23
0.640	18.11	1.05	0.0373	0.06	14.32	0.23
0.665	18.03	1.07	0.0397	0.06	15.28	0.24
0.695	17.92	1.08	0.0416	0.06	16.08	0.24
0.725	17.78	0.97	0.0391	0.05	15.16	0.24
0.755	17.89	0.87	0.0365	0.05	14.13	0.24
0.785	17.90	0.89	0.0387	0.05	14.95	0.24
0.820	17.91	0.88	0.0400	0.05	15.45	0.24
0.855	17.93	0.88	0.0417	0.05	16.12	0.24
0.895	17.96	0.90	0.0449	0.05	17.31	0.24
0.930	17.97	0.94	0.0484	0.05	18.69	0.24
0.970	17.97	0.99	0.0531	0.05	20.49	0.24
1.015	17.95	1.04	0.0587	0.06	22.67	0.24
1.055	17.92	1.08	0.0636	0.06	24.56	0.24
1.100	17.84	1.08	0.0661	0.06	25.60	0.24
1.150	17.86	1.04	0.0666	0.06	25.77	0.24
1.195	17.89	1.06	0.0703	0.06	27.16	0.24
1.250	17.91	1.10	0.0765	0.06	29.56	0.24
1.300	17.92	1.15	0.0833	0.06	32.17	0.24
1.360	17.91	1.21	0.0918	0.07	35.47	0.24
1.415	17.88	1.26	0.0992	0.07	38.34	0.24
1.475	17.84	1.27	0.1041	0.07	40.28	0.24
1.540	17.87	1.28	0.1095	0.07	42.34	0.24
1.605	17.89	1.33	0.1187	0.07	45.87	0.24
1.675	17.90	1.41	0.1311	0.08	50.66	0.24
1.745	17.87	1.48	0.1434	0.08	55.44	0.24
1.820	17.84	1.51	0.1530	0.08	59.22	0.24
1.900	17.85	1.55	0.1635	0.09	63.25	0.24
1.980	17.88	1.63	0.1799	0.09	69.53	0.24
2.065	17.85	1.75	0.2015	0.10	77.93	0.24
2.155	17.76	1.84	0.2209	0.10	85.64	0.24
2.250	17.70	1.88	0.2346	0.11	91.08	0.24
2.345	17.66	1.92	0.2499	0.11	97.13	0.24
2.445	17.63	1.95	0.2649	0.11	103.03	0.24
2.550	17.61	1.98	0.2814	0.11	109.53	0.24
2.660	17.61	2.03	0.3001	0.12	116.80	0.24
2.775	17.61	2.09	0.3232	0.12	125.78	0.24
2.890	17.59	2.17	0.3490	0.12	135.84	0.24
3.015	17.58	2.25	0.3764	0.13	146.56	0.24
3.145	17.56	2.33	0.4079	0.13	158.87	0.24
3.280	17.54	2.43	0.4426	0.14	172.47	0.24
3.420	17.51	2.52	0.4790	0.14	186.79	0.24
3.570	17.47	2.63	0.5212	0.15	203.39	0.24
3.720	17.44	2.72	0.5631	0.16	219.89	0.24
3.880	17.41	2.82	0.6085	0.16	237.80	0.24
4.045	17.37	2.92	0.6570	0.17	256.99	0.24


FT CARSON SAND , File: 6JN70036
20 deg C, Mv = 28.9%, 1.671 g/cc (dry)
Real
Imaginary
Relative Dielectric Constant
100
10
1
0.1
0.01
0.1
1
10
Frequency - GHz



FT CARSON SAND , File: 6JN70036
20 deg C, Mv = 28.9%, 1.671 g/cc (dry)
Conductivity
Loss Tangent
100
10
1
0.1
0.01
Conductivity - mho/m
10
1
0.1
0.01
0.001
Loss Tangent
0.01
0.1
1
10
Frequency - GHz

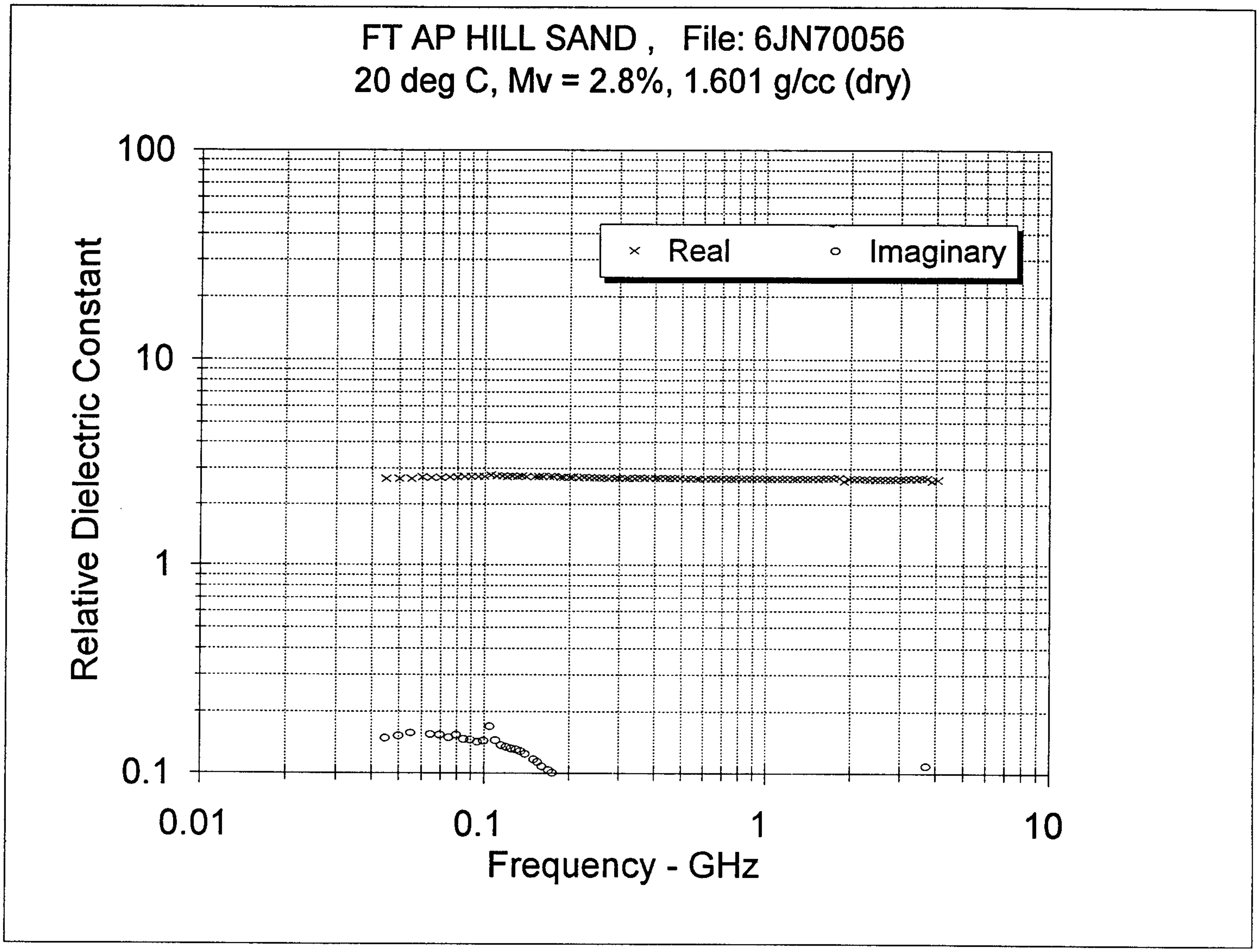

FT CARSON SAND , File: 6JN70036
20 deg C, Mv = 28.9%, 1.671 g/cc (dry)
Attenuation
Phase Velocity
Attenuation - dB/m
Normalized Phase Velocity
Frequency - GHz
1000
100
10
1
0.01
0.1
1
10
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

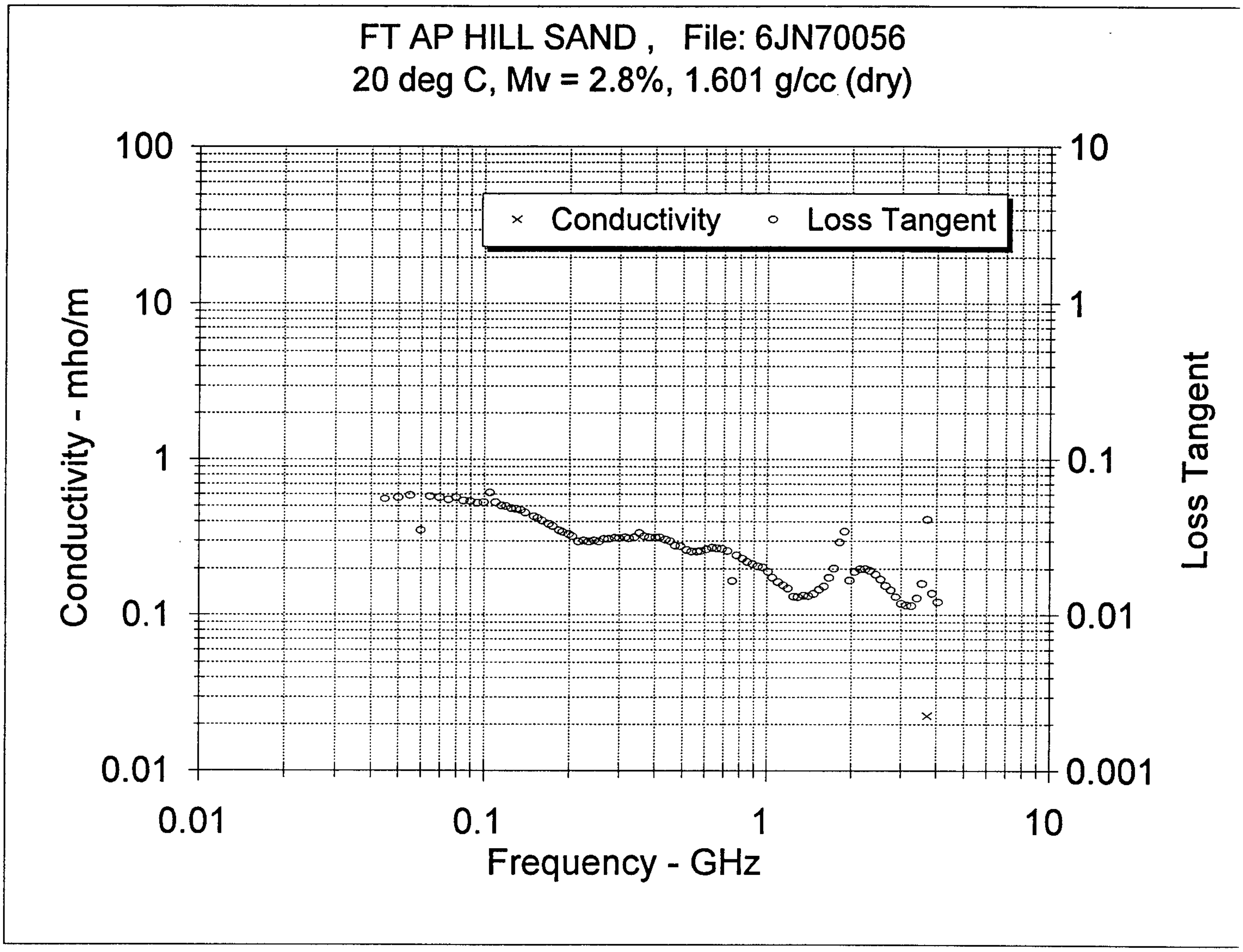
6JN70056
Ft AP Hill Sand
4.9
3
2.79
20
1.601

FT AP HILL SAND , File: 6JN70056
20 deg C, Mv = 2.8%, 1.601 g/cc (dry)

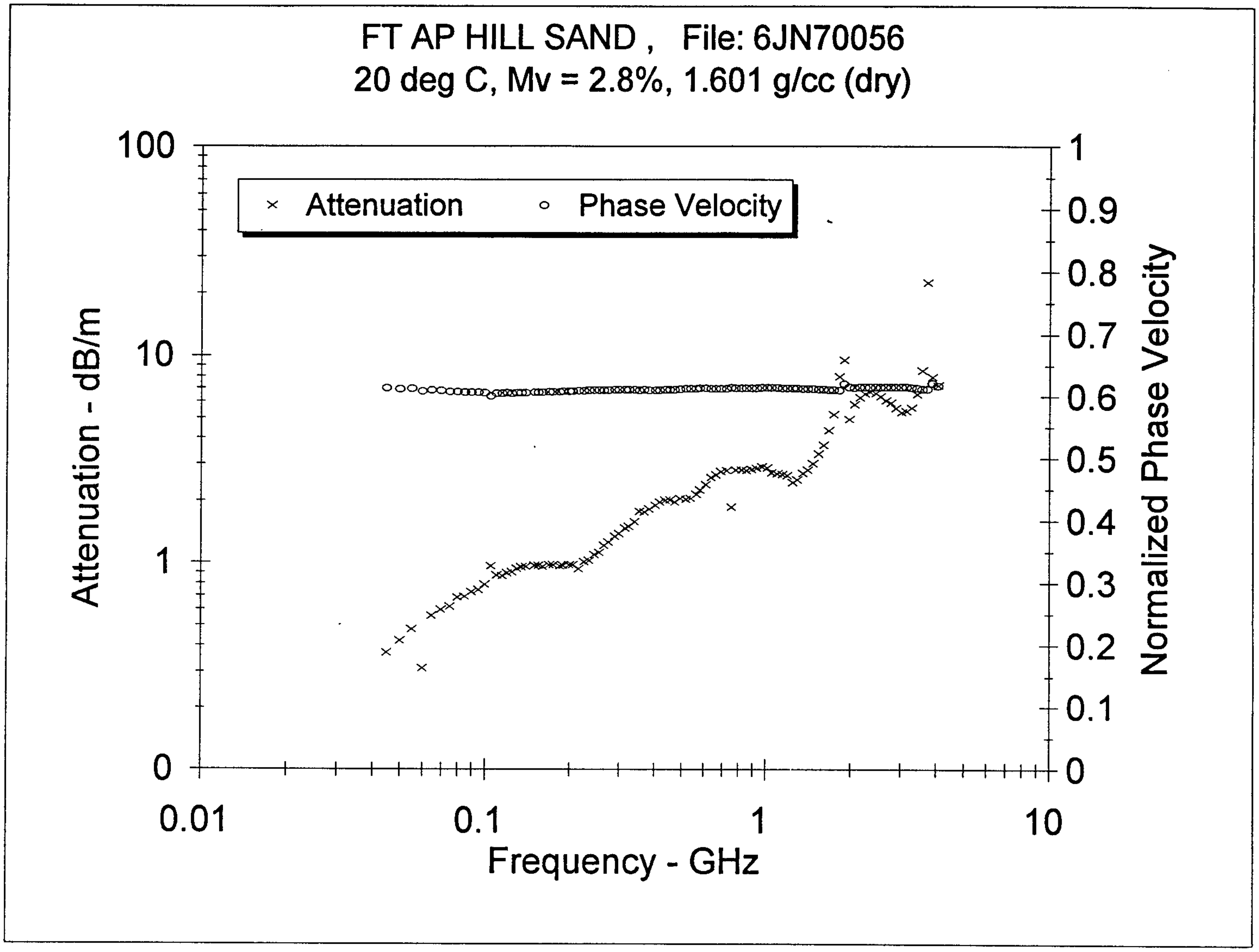
Freq GHz	Re(eps)	Im(eps)	Cond mho/m	Loss Tan	Attn dB/m	Norm Vel
0.045	2.65	0.15	0.0004	0.06	0.37	0.61
0.050	2.66	0.15	0.0004	0.06	0.42	0.61
0.055	2.66	0.16	0.0005	0.06	0.48	0.61
0.060	2.70	0.09	0.0003	0.03	0.31	0.61
0.065	2.69	0.15	0.0006	0.06	0.56	0.61
0.070	2.69	0.15	0.0006	0.06	0.59	0.61
0.075	2.70	0.15	0.0006	0.06	0.62	0.61
0.080	2.71	0.15	0.0007	0.06	0.68	0.61
0.085	2.71	0.15	0.0007	0.05	0.69	0.61
0.090	2.71	0.15	0.0007	0.05	0.73	0.61
0.095	2.71	0.14	0.0007	0.05	0.74	0.61
0.100	2.72	0.14	0.0008	0.05	0.79	0.61
0.105	2.76	0.17	0.0010	0.06	0.97	0.60
0.110	2.72	0.14	0.0009	0.05	0.87	0.61
0.115	2.72	0.14	0.0009	0.05	0.87	0.61
0.120	2.72	0.14	0.0009	0.05	0.89	0.61
0.125	2.72	0.13	0.0009	0.05	0.91	0.61
0.130	2.72	0.13	0.0009	0.05	0.94	0.61
0.135	2.72	0.13	0.0010	0.05	0.95	0.61
0.140	2.72	0.12	0.0010	0.05	0.96	0.61
0.150	2.72	0.12	0.0010	0.04	0.97	0.61
0.155	2.71	0.11	0.0010	0.04	0.97	0.61
0.160	2.71	0.11	0.0010	0.04	0.96	0.61
0.170	2.71	0.10	0.0010	0.04	0.98	0.61
0.175	2.71	0.10	0.0010	0.04	0.97	0.61
0.185	2.70	0.09	0.0010	0.03	0.97	0.61
0.190	2.70	0.09	0.0010	0.03	0.97	0.61
0.200	2.70	0.09	0.0010	0.03	0.98	0.61
0.205	2.70	0.09	0.0010	0.03	0.98	0.61
0.215	2.69	0.08	0.0009	0.03	0.94	0.61
0.225	2.69	0.08	0.0010	0.03	1.01	0.61
0.235	2.69	0.08	0.0010	0.03	1.03	0.61
0.245	2.69	0.08	0.0011	0.03	1.10	0.61
0.255	2.68	0.08	0.0011	0.03	1.12	0.61
0.265	2.68	0.08	0.0012	0.03	1.21	0.61
0.275	2.68	0.08	0.0013	0.03	1.26	0.61
0.290	2.67	0.08	0.0013	0.03	1.34	0.61
0.300	2.67	0.08	0.0014	0.03	1.39	0.61
0.315	2.67	0.08	0.0015	0.03	1.47	0.61
0.325	2.67	0.08	0.0015	0.03	1.49	0.61
0.340	2.67	0.08	0.0016	0.03	1.58	0.61
0.355	2.69	0.09	0.0018	0.03	1.78	0.61
0.370	2.68	0.09	0.0018	0.03	1.76	0.61
0.385	2.68	0.08	0.0018	0.03	1.81	0.61
0.405	2.68	0.08	0.0019	0.03	1.89	0.61

0.420	2.68	0.08	0.0020	0.03	1.96	0.61
0.440	2.68	0.08	0.0020	0.03	1.99	0.61
0.455	2.68	0.08	0.0020	0.03	2.01	0.61
0.475	2.67	0.07	0.0020	0.03	1.97	0.61
0.495	2.67	0.07	0.0020	0.03	2.04	0.61
0.520	2.66	0.07	0.0020	0.03	2.01	0.61
0.540	2.66	0.07	0.0020	0.03	2.04	0.61
0.565	2.66	0.07	0.0021	0.03	2.14	0.61
0.585	2.66	0.07	0.0022	0.03	2.23	0.61
0.610	2.66	0.07	0.0024	0.03	2.38	0.61
0.640	2.66	0.07	0.0026	0.03	2.56	0.61
0.665	2.66	0.07	0.0026	0.03	2.64	0.61
0.695	2.66	0.07	0.0027	0.03	2.74	0.61
0.725	2.66	0.07	0.0028	0.03	2.78	0.61
0.755	2.65	0.04	0.0018	0.02	1.85	0.61
0.785	2.65	0.06	0.0028	0.02	2.80	0.61
0.820	2.65	0.06	0.0028	0.02	2.80	0.61
0.855	2.65	0.06	0.0028	0.02	2.78	0.61
0.895	2.65	0.06	0.0028	0.02	2.81	0.61
0.930	2.65	0.05	0.0028	0.02	2.84	0.61
0.970	2.65	0.05	0.0029	0.02	2.91	0.61
1.015	2.65	0.05	0.0028	0.02	2.86	0.61
1.055	2.65	0.05	0.0027	0.02	2.72	0.61
1.100	2.65	0.04	0.0027	0.02	2.67	0.61
1.150	2.65	0.04	0.0026	0.02	2.65	0.61
1.195	2.65	0.04	0.0026	0.01	2.63	0.61
1.250	2.65	0.03	0.0024	0.01	2.44	0.61
1.300	2.66	0.03	0.0025	0.01	2.51	0.61
1.360	2.66	0.04	0.0027	0.01	2.69	0.61
1.415	2.66	0.04	0.0028	0.01	2.80	0.61
1.475	2.66	0.04	0.0030	0.01	3.00	0.61
1.540	2.66	0.04	0.0033	0.01	3.35	0.61
1.605	2.67	0.04	0.0037	0.02	3.68	0.61
1.675	2.67	0.05	0.0043	0.02	4.33	0.61
1.745	2.67	0.05	0.0052	0.02	5.19	0.61
1.820	2.68	0.08	0.0079	0.03	7.91	0.61
1.900	2.59	0.09	0.0094	0.03	9.51	0.62
1.980	2.64	0.04	0.0049	0.02	4.90	0.62
2.065	2.64	0.05	0.0058	0.02	5.80	0.62
2.155	2.64	0.05	0.0063	0.02	6.29	0.62
2.250	2.64	0.05	0.0065	0.02	6.58	0.62
2.345	2.64	0.05	0.0066	0.02	6.67	0.62
2.445	2.63	0.05	0.0065	0.02	6.59	0.62
2.550	2.63	0.04	0.0063	0.02	6.36	0.62
2.660	2.63	0.04	0.0060	0.02	6.07	0.62
2.775	2.63	0.04	0.0059	0.01	5.92	0.62
2.890	2.63	0.03	0.0055	0.01	5.57	0.62
3.015	2.64	0.03	0.0053	0.01	5.29	0.62
3.145	2.64	0.03	0.0054	0.01	5.39	0.62
3.280	2.65	0.03	0.0056	0.01	5.59	0.61
3.420	2.65	0.03	0.0065	0.01	6.48	0.61
3.570	2.67	0.04	0.0084	0.02	8.44	0.61
3.720	2.67	0.11	0.0225	0.04	22.57	0.61
3.880	2.59	0.04	0.0077	0.01	7.85	0.62
4.045	2.62	0.03	0.0071	0.01	7.18	0.62


FT AP HILL SAND , File: 6JN70056
20 deg C, Mv = 2.8%, 1.601 g/cc (dry)
Real
Imaginary
Relative Dielectric Constant
100
10
1
0.1
0.01
0.1
1
10
Frequency - GHz



FT AP HILL SAND , File: 6JN70056
20 deg C, Mv = 2.8%, 1.601 g/cc (dry)
Conductivity
Loss Tangent
Conductivity - mho/m
Loss Tangent
Frequency - GHz
100
10
1
0.1
0.01
10
1
0.1
0.01
0.001
0.01
0.1
1
10

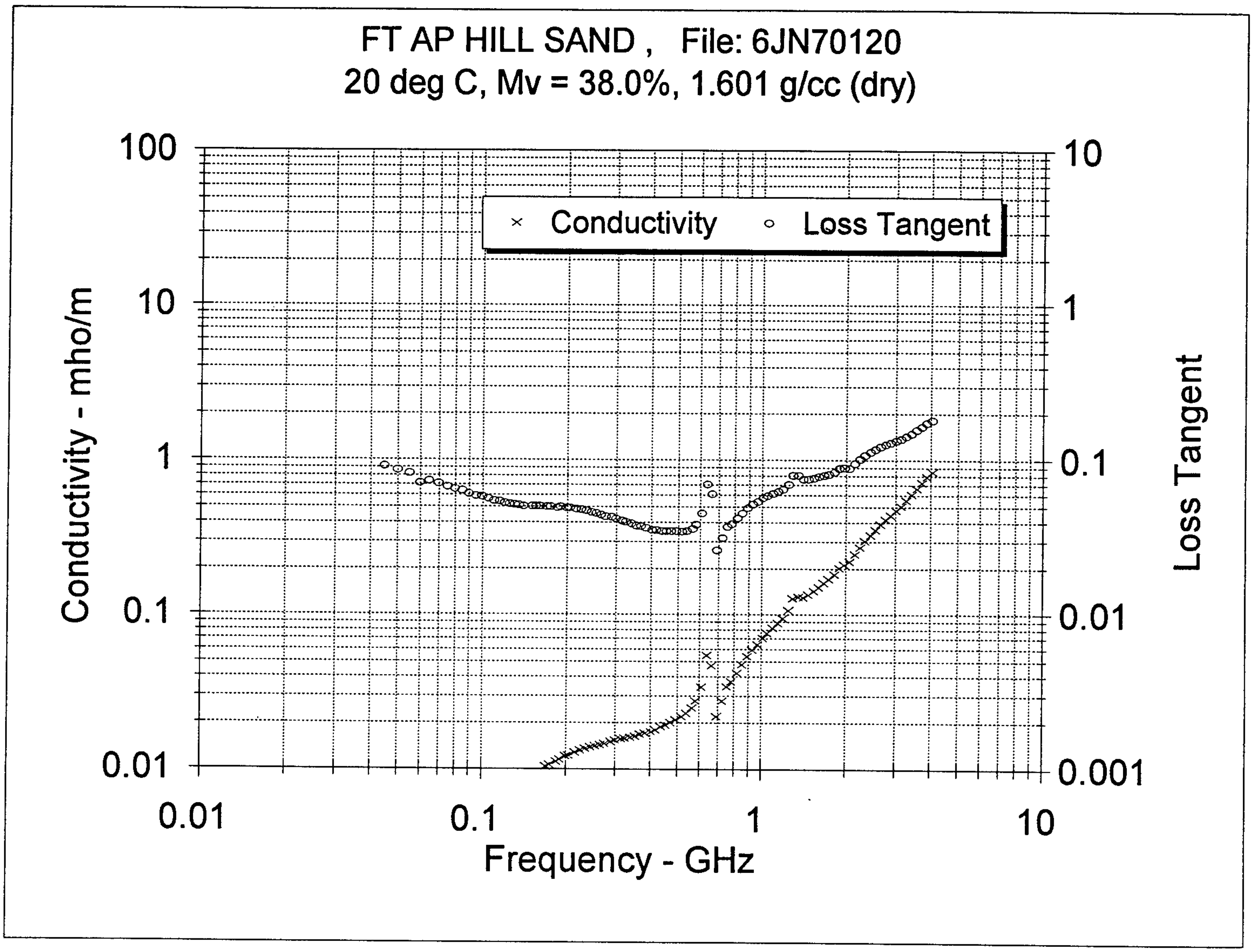


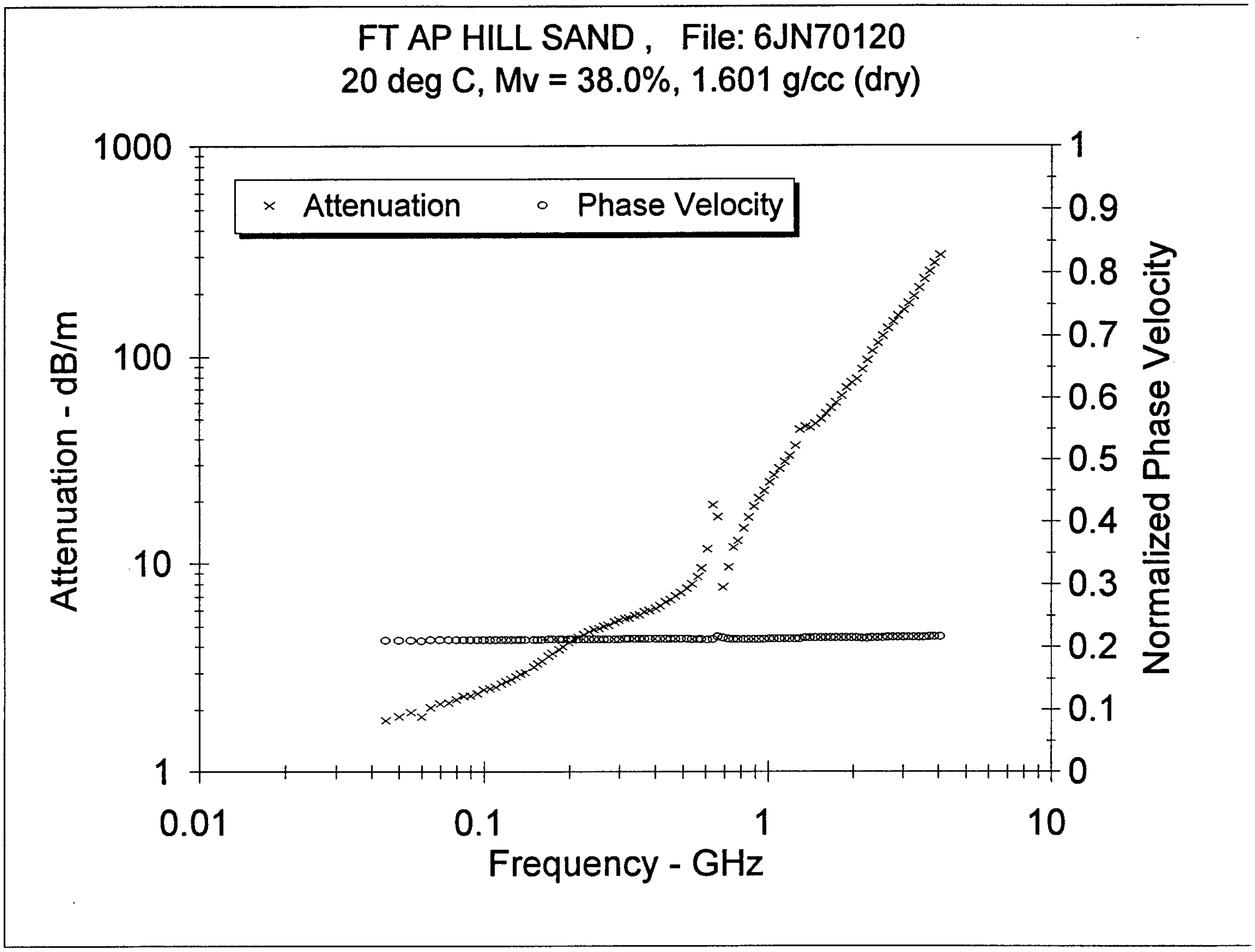
FT AP HILL SAND , File: 6JN70056
20 deg C, Mv = 2.8%, 1.601 g/cc (dry)
Attenuation
Phase Velocity
Attenuation - dB/m
Normalized Phase Velocity
Frequency - GHz
100
10
1
0
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.01
0.1
1
10

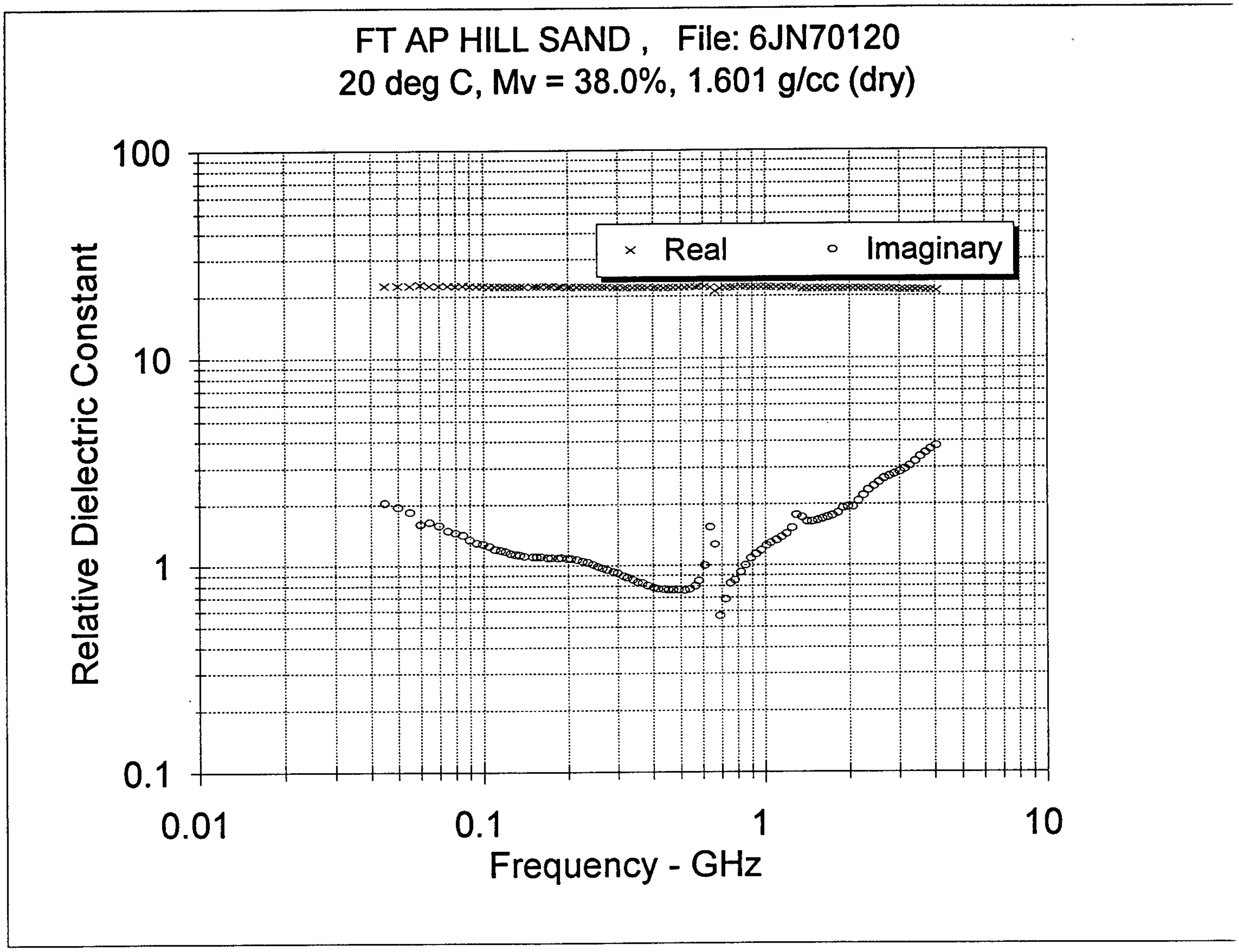
6JN70120
Ft AP Hill Sand
4.9
3
38
20
1.601

FT AP HILL SAND , File: 6JN70120
20 deg C, Mv = 38.0%, 1.601 g/cc (dry)

Freq GHz	Re(eps)	Im(eps)	Cond mho/m	Loss Tan	Attn dB/m	Norm Vel
0.045	22.44	2.04	0.0051	0.09	1.76	0.21
0.050	22.44	1.93	0.0054	0.09	1.85	0.21
0.055	22.37	1.84	0.0056	0.08	1.94	0.21
0.060	22.66	1.61	0.0054	0.07	1.84	0.21
0.065	22.34	1.64	0.0059	0.07	2.05	0.21
0.070	22.31	1.58	0.0061	0.07	2.12	0.21
0.075	22.29	1.49	0.0062	0.07	2.16	0.21
0.080	22.28	1.46	0.0065	0.07	2.25	0.21
0.085	22.33	1.42	0.0067	0.06	2.32	0.21
0.090	22.21	1.35	0.0067	0.06	2.34	0.21
0.095	22.20	1.30	0.0069	0.06	2.38	0.21
0.100	22.19	1.29	0.0072	0.06	2.48	0.21
0.105	22.17	1.25	0.0073	0.06	2.53	0.21
0.110	22.16	1.21	0.0074	0.05	2.57	0.21
0.115	22.14	1.20	0.0076	0.05	2.66	0.21
0.120	22.13	1.18	0.0079	0.05	2.73	0.21
0.125	22.12	1.15	0.0080	0.05	2.78	0.21
0.130	22.10	1.14	0.0083	0.05	2.87	0.21
0.135	22.10	1.14	0.0085	0.05	2.96	0.21
0.140	22.10	1.12	0.0087	0.05	3.02	0.21
0.150	22.09	1.11	0.0092	0.05	3.22	0.21
0.155	22.09	1.11	0.0096	0.05	3.32	0.21
0.160	22.08	1.11	0.0099	0.05	3.43	0.21
0.170	22.08	1.10	0.0104	0.05	3.62	0.21
0.175	22.06	1.10	0.0107	0.05	3.72	0.21
0.185	22.05	1.09	0.0112	0.05	3.90	0.21
0.190	22.07	1.10	0.0116	0.05	4.03	0.21
0.200	22.04	1.08	0.0121	0.05	4.20	0.21
0.205	22.03	1.08	0.0123	0.05	4.30	0.21
0.215	22.02	1.07	0.0128	0.05	4.45	0.21
0.225	22.01	1.06	0.0132	0.05	4.60	0.21
0.235	22.00	1.04	0.0136	0.05	4.74	0.21
0.245	21.98	1.02	0.0139	0.05	4.84	0.21
0.255	21.97	0.99	0.0141	0.05	4.91	0.21
0.265	21.96	0.98	0.0144	0.04	5.02	0.21
0.275	21.95	0.96	0.0146	0.04	5.10	0.21
0.290	21.94	0.94	0.0151	0.04	5.27	0.21
0.300	21.94	0.92	0.0154	0.04	5.36	0.21
0.315	21.91	0.89	0.0156	0.04	5.45	0.21
0.325	21.89	0.87	0.0158	0.04	5.52	0.21
0.340	21.88	0.85	0.0161	0.04	5.65	0.21
0.355	21.86	0.83	0.0163	0.04	5.71	0.21
0.370	21.85	0.82	0.0169	0.04	5.91	0.21
0.385	21.84	0.80	0.0171	0.04	5.98	0.21
0.405	21.83	0.78	0.0175	0.04	6.14	0.21


FT AP HILL SAND , File: 6JN70120
20 deg C, Mv = 38.0%, 1.601 g/cc (dry)
Conductivity
Loss Tangent
Conductivity - mho/m
Loss Tangent
Frequency - GHz
100
10
1
0.1
0.01
10
1
0.1
0.01
0.001
0.01
0.1
1
10


FT AP HILL SAND , File: 6JN70120
20 deg C, Mv = 38.0%, 1.601 g/cc (dry)
Attenuation
Phase Velocity
Attenuation - dB/m
Normalized Phase Velocity
Frequency - GHz
1000
100
10
1
0.01
0.1
1
10
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0


FT AP HILL SAND , File: 6JN70120
20 deg C, Mv = 38.0%, 1.601 g/cc (dry)
Relative Dielectric Constant
100
10
1
0.1
0.01
0.1
1
10
Frequency - GHz
Real
Imaginary

0.420	21.83	0.77	0.0180	0.04	6.32	0.21
0.440	21.83	0.77	0.0188	0.04	6.56	0.21
0.455	21.84	0.76	0.0192	0.03	6.74	0.21
0.475	21.85	0.76	0.0201	0.03	7.01	0.21
0.495	21.87	0.76	0.0209	0.03	7.31	0.21
0.520	21.91	0.76	0.0219	0.03	7.64	0.21
0.540	21.95	0.77	0.0230	0.03	8.02	0.21
0.565	22.02	0.79	0.0249	0.04	8.67	0.21
0.585	22.08	0.84	0.0275	0.04	9.57	0.21
0.610	22.17	1.00	0.0339	0.05	11.78	0.21
0.640	21.93	1.54	0.0548	0.07	19.13	0.21
0.665	21.03	1.27	0.0470	0.06	16.77	0.22
0.695	21.62	0.57	0.0219	0.03	7.71	0.22
0.725	21.82	0.69	0.0276	0.03	9.67	0.21
0.755	21.93	0.82	0.0343	0.04	11.98	0.21
0.785	21.93	0.85	0.0370	0.04	12.90	0.21
0.820	21.95	0.93	0.0422	0.04	14.74	0.21
0.855	21.95	1.00	0.0476	0.05	16.62	0.21
0.895	21.95	1.08	0.0538	0.05	18.78	0.21
0.930	21.94	1.14	0.0589	0.05	20.55	0.21
0.970	21.91	1.19	0.0642	0.05	22.42	0.21
1.015	21.89	1.25	0.0705	0.06	24.64	0.21
1.055	21.87	1.29	0.0759	0.06	26.53	0.21
1.100	21.84	1.33	0.0816	0.06	28.53	0.21
1.150	21.83	1.38	0.0881	0.06	30.84	0.21
1.195	21.83	1.43	0.0947	0.07	33.13	0.21
1.250	21.88	1.53	0.1061	0.07	37.09	0.21
1.300	21.81	1.76	0.1272	0.08	44.50	0.21
1.360	21.54	1.72	0.1301	0.08	45.82	0.22
1.415	21.52	1.64	0.1289	0.08	45.42	0.22
1.475	21.55	1.64	0.1343	0.08	47.31	0.22
1.540	21.54	1.66	0.1421	0.08	50.03	0.22
1.605	21.54	1.69	0.1508	0.08	53.12	0.22
1.675	21.53	1.72	0.1604	0.08	56.49	0.22
1.745	21.54	1.75	0.1700	0.08	59.88	0.22
1.820	21.56	1.81	0.1830	0.08	64.42	0.22
1.900	21.55	1.91	0.2014	0.09	70.91	0.22
1.980	21.47	1.92	0.2119	0.09	74.71	0.22
2.065	21.56	1.93	0.2213	0.09	77.88	0.22
2.155	21.60	2.06	0.2471	0.10	86.85	0.21
2.250	21.59	2.20	0.2747	0.10	96.57	0.21
2.345	21.56	2.32	0.3025	0.11	106.42	0.22
2.445	21.51	2.43	0.3298	0.11	116.12	0.22
2.550	21.46	2.53	0.3586	0.12	126.43	0.22
2.660	21.39	2.63	0.3888	0.12	137.26	0.22
2.775	21.33	2.70	0.4164	0.13	147.20	0.22
2.890	21.29	2.77	0.4445	0.13	157.25	0.22
3.015	21.26	2.84	0.4753	0.13	168.25	0.22
3.145	21.26	2.91	0.5096	0.14	180.39	0.22
3.280	21.26	3.03	0.5523	0.14	195.42	0.22
3.420	21.25	3.17	0.6036	0.15	213.59	0.22
3.570	21.22	3.34	0.6624	0.16	234.52	0.22
3.720	21.16	3.50	0.7230	0.17	256.25	0.22
3.880	21.08	3.65	0.7879	0.17	279.68	0.22
4.045	20.99	3.79	0.8522	0.18	303.01	0.22

23 August 1996

Data Report

Dielectric Properties

Landmine Filler

Prepared for: Regina Dugan
U.S. Department of Defense
Advanced Research Projects Agency (ARPA)
3701 North Fairfax Drive
Arlington, VA 22203-1714
703-696-2296

Prepared by: John O. Curtis
U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Introduction

This report contains dielectric property measurement results for an unknown substance used to fill training landmines. The original data were collected in the form of the real and imaginary parts of the complex dielectric constant versus frequency. The data collection apparatus was a Hewlet-Packard 8510C Vector Network Analyzer System with an S-Parameter Test Set. Software developed at the U.S. Army Engineer Waterways Experiment Station was used to convert S-parameter measurements at selected frequencies into a complex dielectric constant. The material was assumed to be nonmagnetic. Other useful electromagnetic properties were calculated from the dielectric constant and frequency, including an equivalent electrical conductivity, the loss tangent, power attenuation, and a normalized phase velocity. The section entitled, "Fundamental Relationships," contains the formulae used to calculate these properties. Data were collected at three sample temperatures: -10°C, 20°C, and 40°C.

Measurement results and calculated parameters are displayed in two ways. The first is properties tabulated and plotted at two frequencies, 100 MHz and 500 MHz, which were chosen to bracket the normal range of operating frequencies for ground penetrating radars. The second set of data includes both tables and plots of laboratory results and calculated parameters displayed as a function of frequency to establish whether or not this material is dispersive.

For additional details on how the data were collected, please contact me at the U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, (voice: 601-634-2855, FAX: 601-634-2732, e-mail: curtisj@ex1.wes.army.mil).

Sample Preparation

The sample holder used for these measurements is a brass coaxial apparatus having a rectangular cross section cavity with dimensions of 10 cm, by 0.75 cm, by 0.75 cm. The landmine filler, a red, wax-like substance, was melted in a laboratory beaker and poured into the sample holder. Since the volume of the sample holder is precisely known, it was possible to determine the sample density as being 1.66 g/cc (ordinary waxes have densities slightly less than 1.0 g/cc).

Fundamental Relationships

Assuming plane harmonic wave propagation in a lossy, non-magnetic, unbounded medium, the wave amplitude function may be written:

$$e^{i(kx - \omega t)}$$

where

$k \quad = \beta + i\alpha \quad = \omega N/c$

is the complex propagation constant,

β is the phase constant,

α is the amplitude attenuation factor,

ω is the radial frequency,

N is the complex index of refraction,

c is the velocity of light in a vacuum,

i is the symbol designating an imaginary quantity = $\sqrt{-1}$,

x is a space coordinate, and

t is time.

Furthermore,

$$N^2 = \epsilon = \epsilon' + \epsilon''$$

where ϵ is the relative complex dielectric constant, which, along with the electrical conductivity from Ohm's Law, represents the electrical properties of the medium. The interpretation of these properties as used in this study is that the conductivity, σ , accounts for current due to free charged particle motion, while the imaginary part of the complex dielectric constant, ϵ'' , accounts for displacement current losses (those due to the electric polarization of the medium). When both conduction and displacement currents are considered, one finds two terms in Ampere's law for current flow that represent losses (or a shift in phase), one containing the electrical conductivity and one containing the imaginary part of the dielectric constant. While these two terms account

for different loss mechanisms, most researchers use only one term or the other to identify losses, with many users preferring to deal with the concept of electrical conductivity. In MKS units, the relationship between the two quantities is taken to be

$$\sigma = \epsilon'' \epsilon_0 \omega$$

where the units of conductivity are mhos/meter (or siemens/meter) and ϵ_0 is the permittivity of free space (8.85×10^{-12} farads/meter).

Squaring the expression for the complex propagation constant, substituting the expression for the square of the complex index of refraction, and equating real and imaginary components, one obtains two algebraic equations that relate the amplitude attenuation factor and phase constant to the complex dielectric constant:

$$\beta^2 - \alpha^2 = \frac{\omega^2}{c^2}\epsilon'$$

and

$$\alpha\beta = \frac{\omega^2 \epsilon''}{2c^2}$$

Solving these equations for the amplitude attenuation factor and for the phase constant results in the following expressions:

$$\alpha = \frac{\omega}{c}\left(\frac{\epsilon'}{2}\left(\sqrt{1 + \left(\frac{\epsilon''}{\epsilon'}\right)^2} - 1\right)\right)^{1/2}$$

and

$$\beta = \frac{\omega}{c}\left(\frac{\epsilon'}{2}\left(\sqrt{1 + \left(\frac{\epsilon''}{\epsilon'}\right)^2} + 1\right)\right)^{1/2}$$

The ϵ''/ϵ' ratio is also referred to as the loss tangent. Some researchers prefer to work with the electrical conductivity in place of the dielectric loss term.

Plane waves of constant phase will propagate with a velocity

$$v = \frac{\omega}{\beta} = c\left(\frac{\epsilon'}{2}\left(\sqrt{1 + \left(\frac{\epsilon''}{\epsilon'}\right)^2} + 1\right)\right)^{-1/2}$$

This phase velocity is not necessarily the speed with which the energy of the wave propagates through the

medium. The latter is refered to as the group velocity and can be calculated as the rate of change of radial frequency with respect to the phase constant. However, as long as the phase velocity is relatively constant over the range of frequencies of interest, then there is little difference between phase velocity and group velocity.

The power intensity of the plane electromagnetic wave decreases exponentially with depth of penetration by the factor, $e^{-2\alpha x}$, or, in one unit of distance traveled, a decrease of $e^{-2\alpha}$. Power attenuation expressed in decibels per meter can then be written as:

$$PL = -8.6859 \, \frac{\omega}{c} \left(\frac{\epsilon'}{2} \left(\sqrt{1 + \left(\frac{\epsilon''}{\epsilon'} \right)^2} - 1 \right) \right)^{1/2}$$

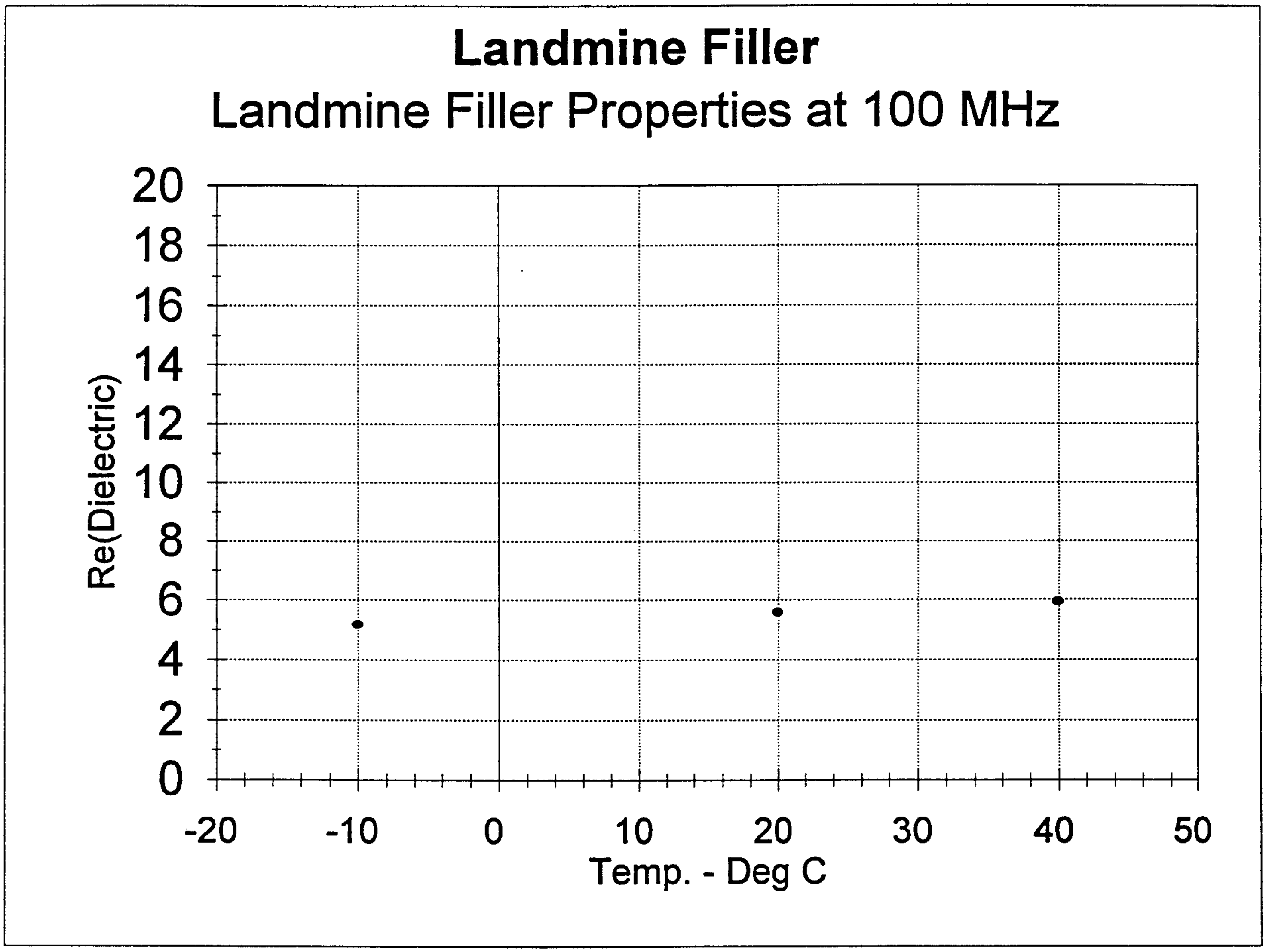
Landmine Filler
Properties at 100 MHz and 500 MHz

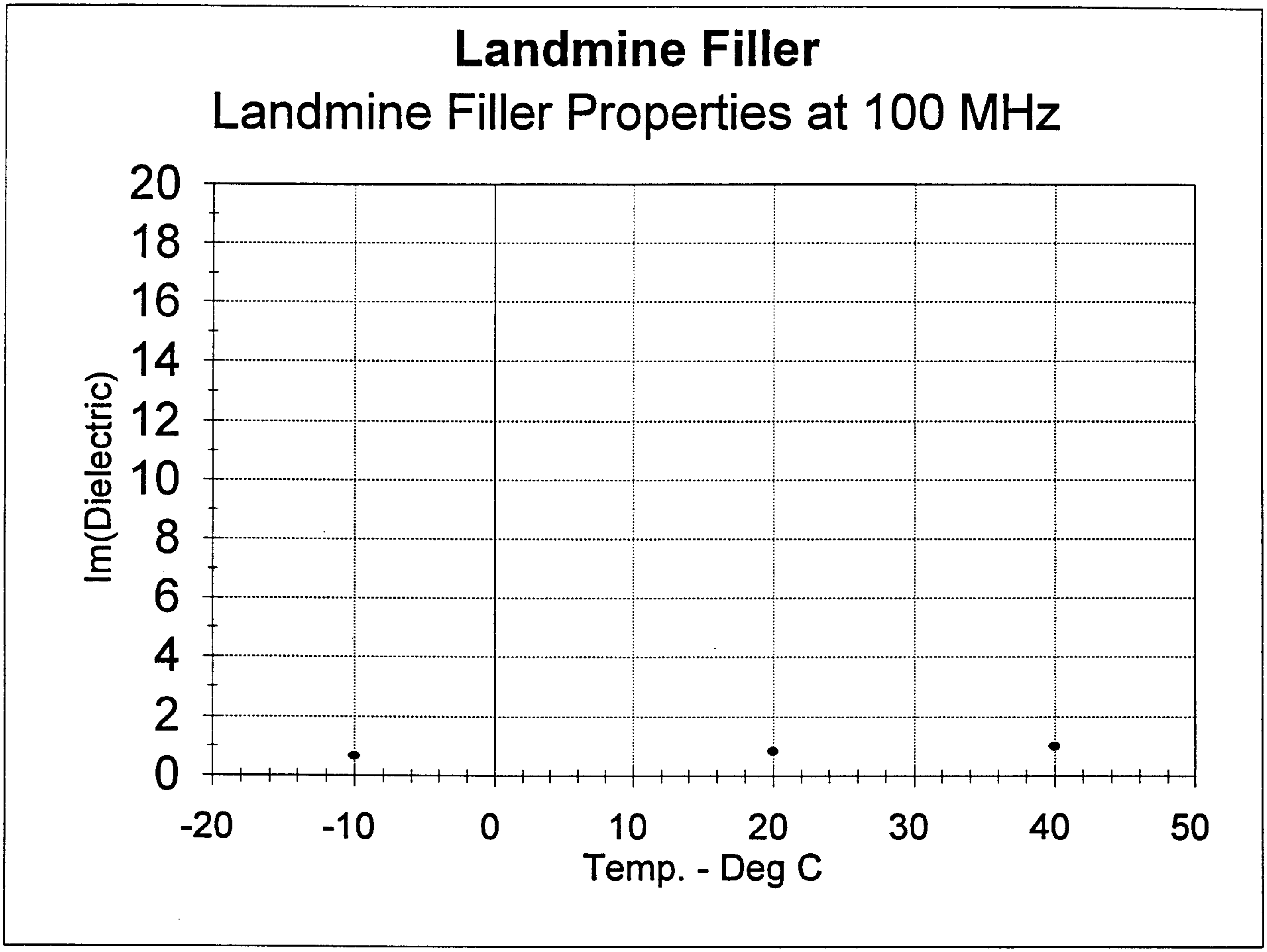
Landmine Filler Properties at 100 MHz

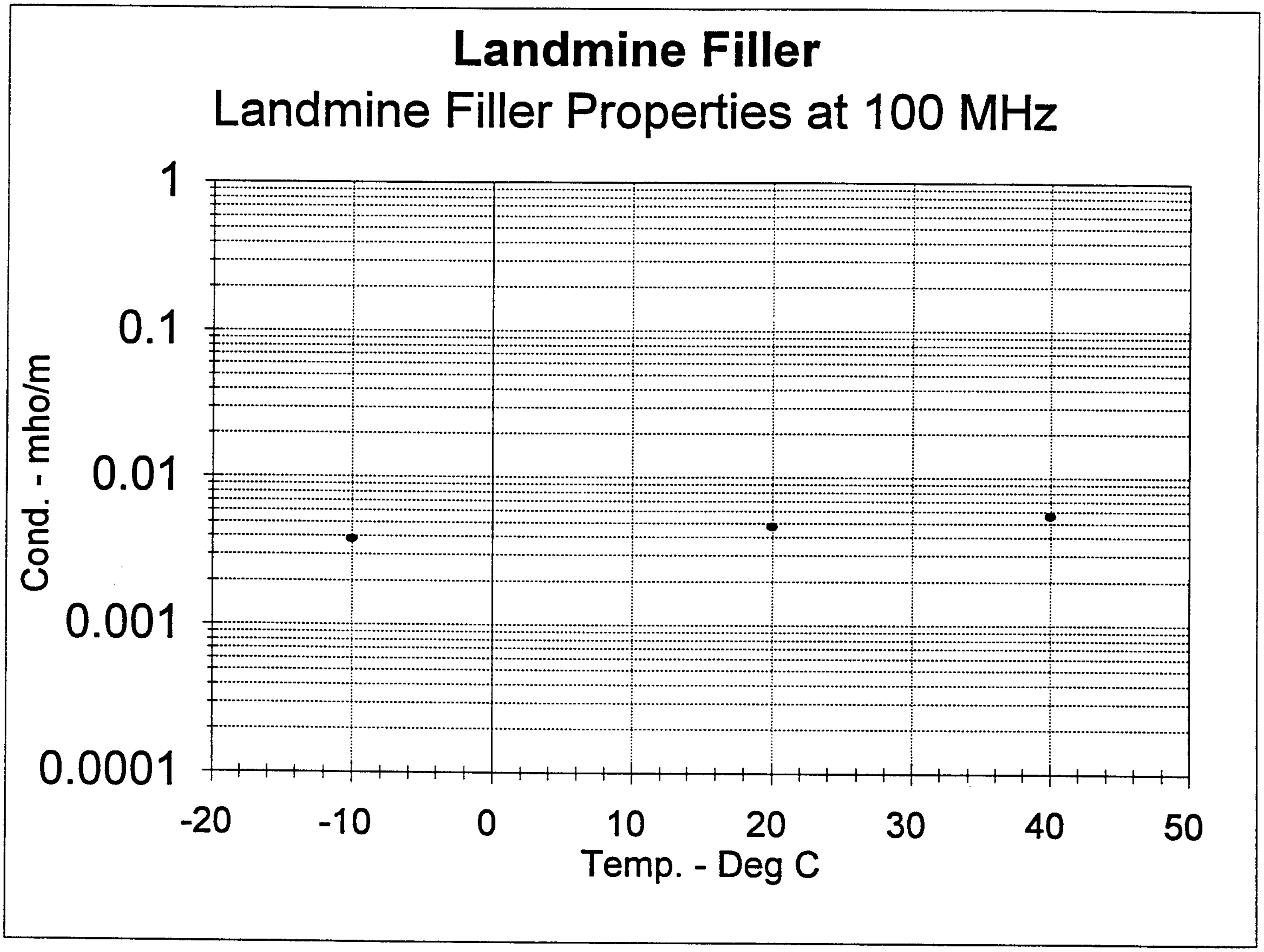
Temp. - Deg C	Re(Dielectric)	Im(Dielectric)	Cond. - mho/m	Loss Tangent	Attn. - dB/m	Norm. Velocity
-10	5.1842	0.6803	0.0038	0.1312	2.7117	0.4383
20	5.5858	0.848	0.0047	0.1518	3.2542	0.4219
40	5.942	1.0076	0.0056	0.1696	3.7463	0.4088

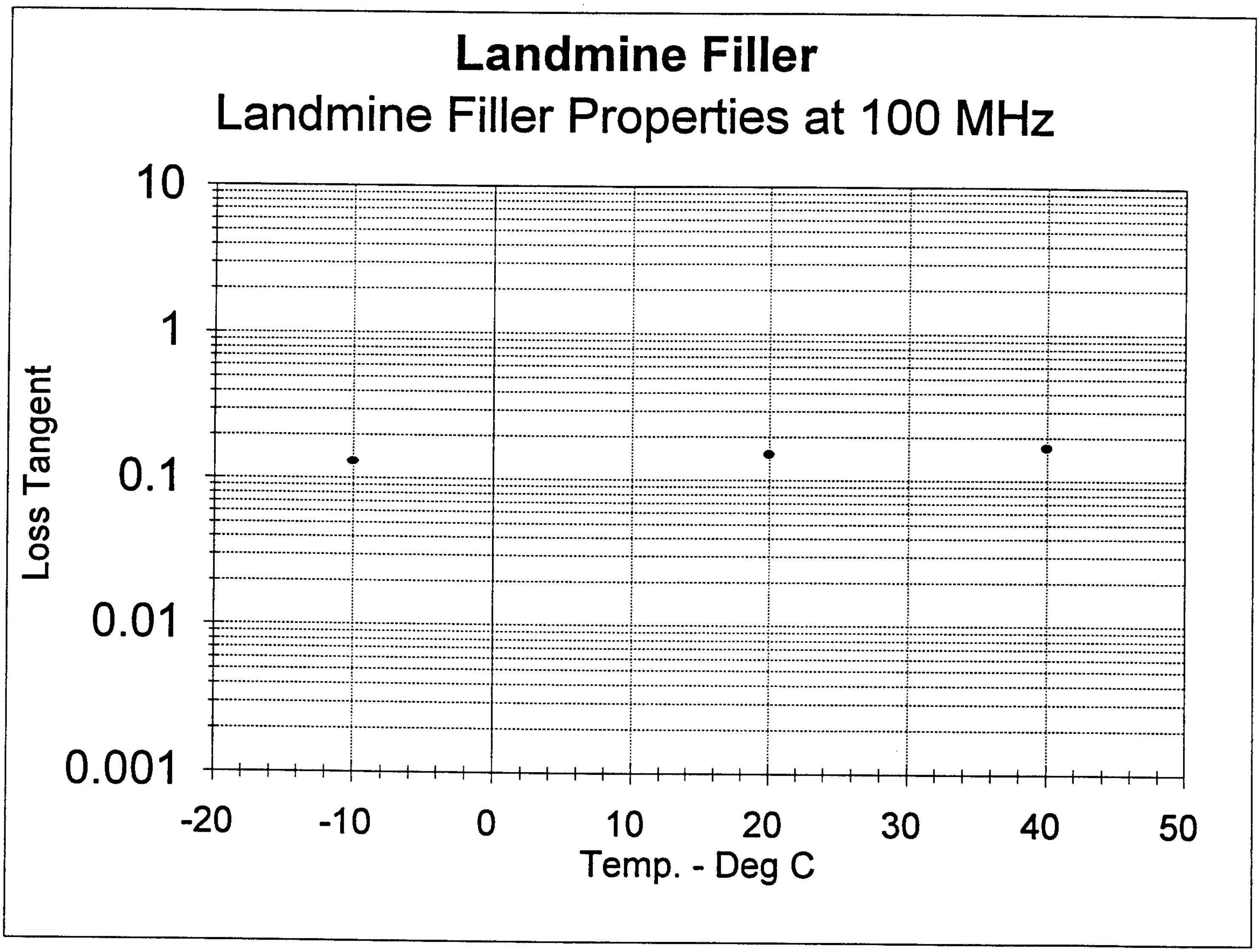
Landmine Filler Properties at 500 MHz

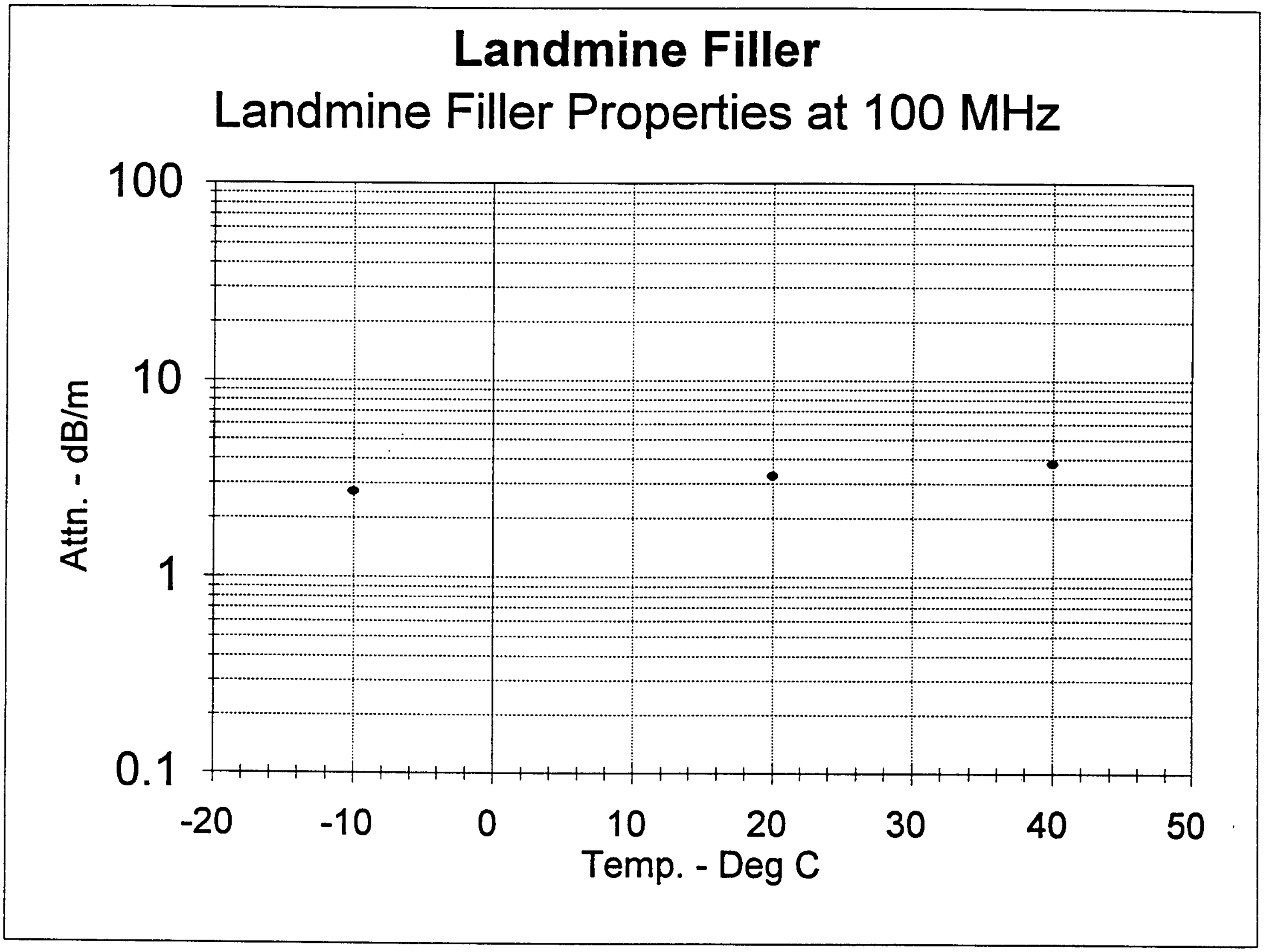
Temp. - Deg C	Re(Dielectric)	Im(Dielectric)	Cond. - mho/m	Loss Tangent	Attn. - dB/m	Norm. Velocity
-10	4.5803	0.4804	0.0132	0.1049	10.0929	0.4666
20	4.8118	0.5985	0.0165	0.1244	12.2613	0.455
40	5.0153	0.7115	0.0196	0.1419	14.2686	0.4454

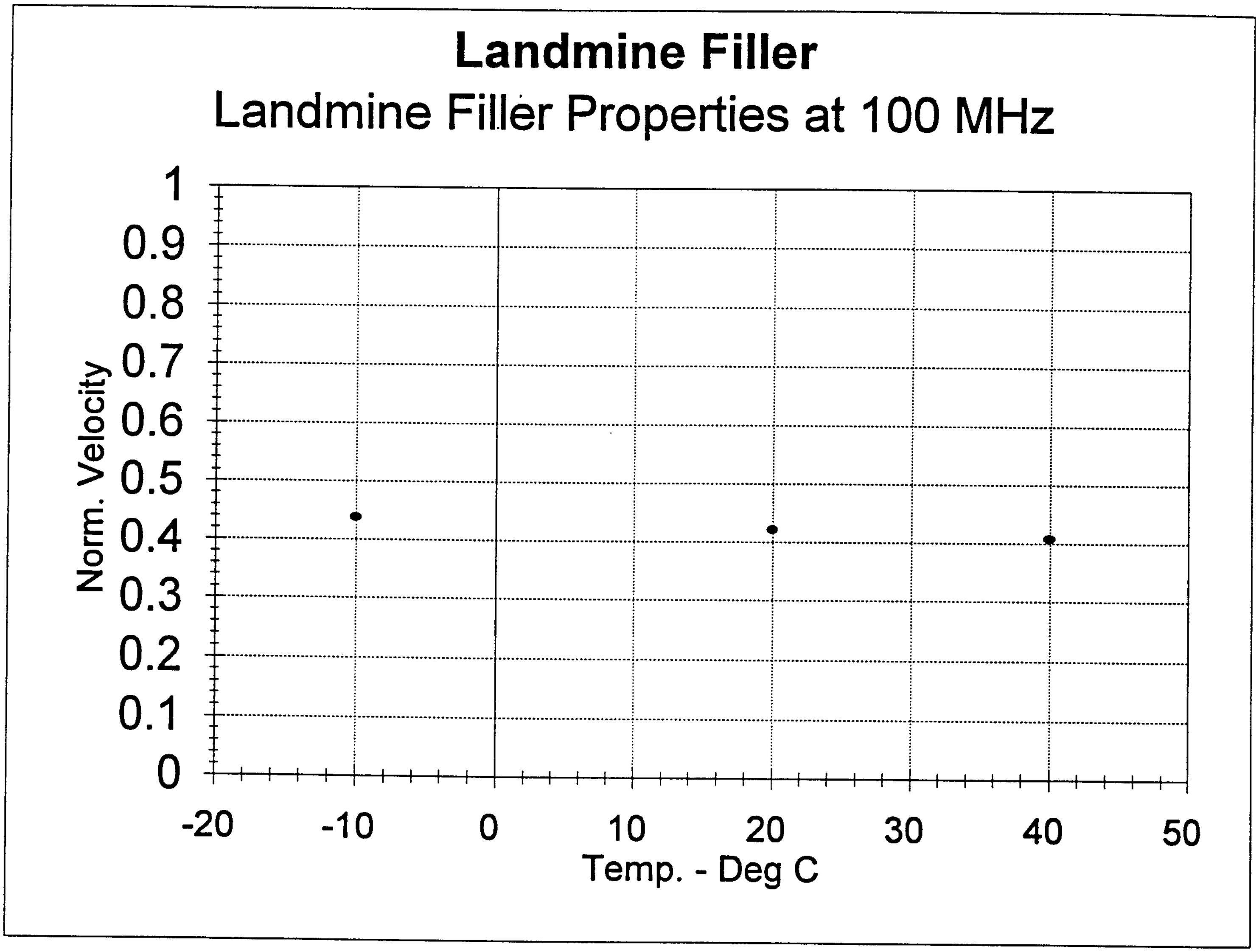

Landmine Filler
Landmine Filler Properties at 100 MHz
20
18
16
14
12
10
8
6
4
2
0
Re(Dielectric)
-20
-10
0
10
20
30
40
50
Temp. - Deg C


Landmine Filler
Landmine Filler Properties at 100 MHz
Im(Dielectric)
20
18
16
14
12
10
8
6
4
2
0
-20
-10
0
10
20
30
40
50
Temp. - Deg C

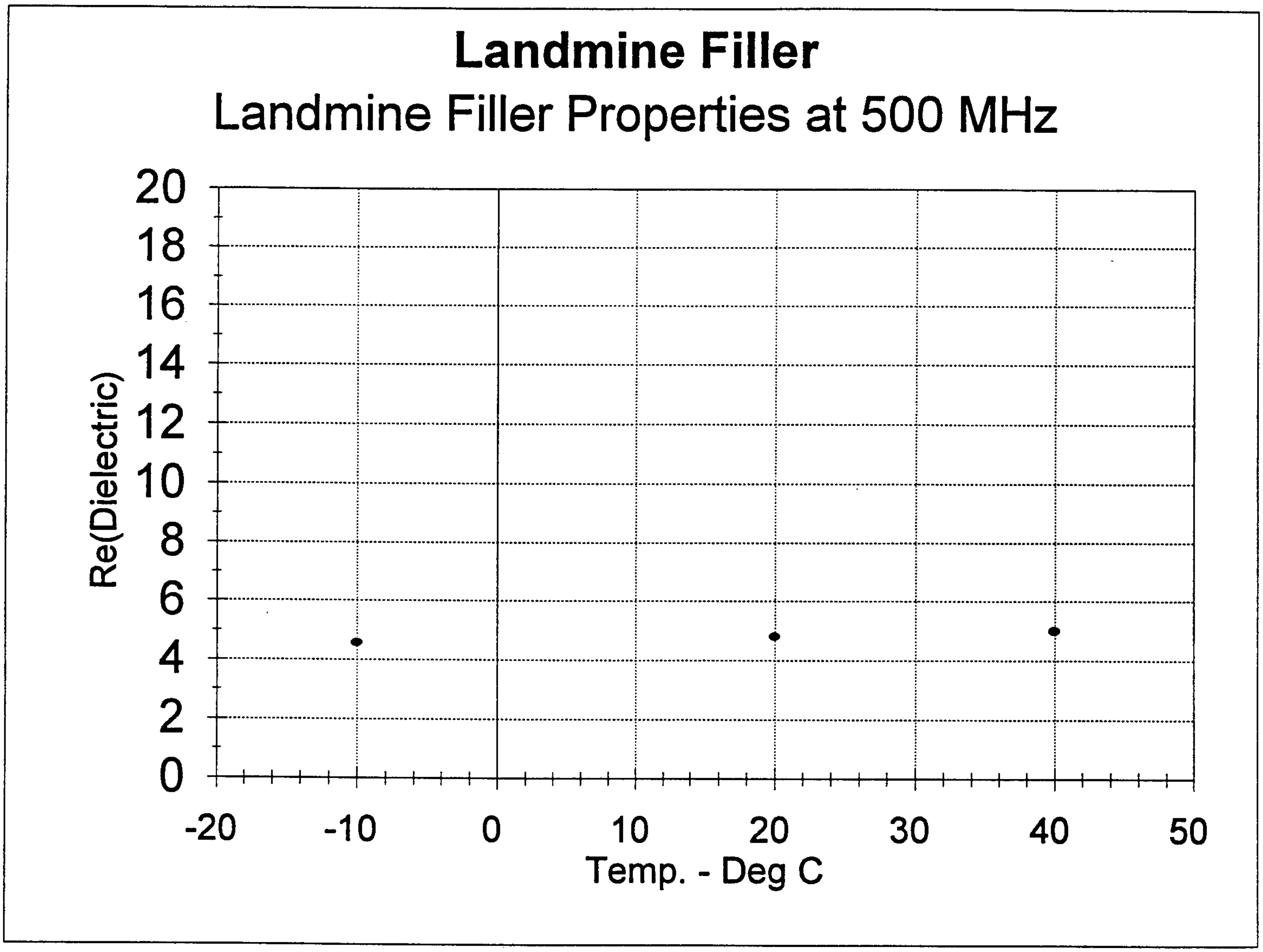

Landmine Filler
Landmine Filler Properties at 100 MHz
Cond. - mho/m
1
0.1
0.01
0.001
0.0001
-20
-10
0
10
20
30
40
50
Temp. - Deg C

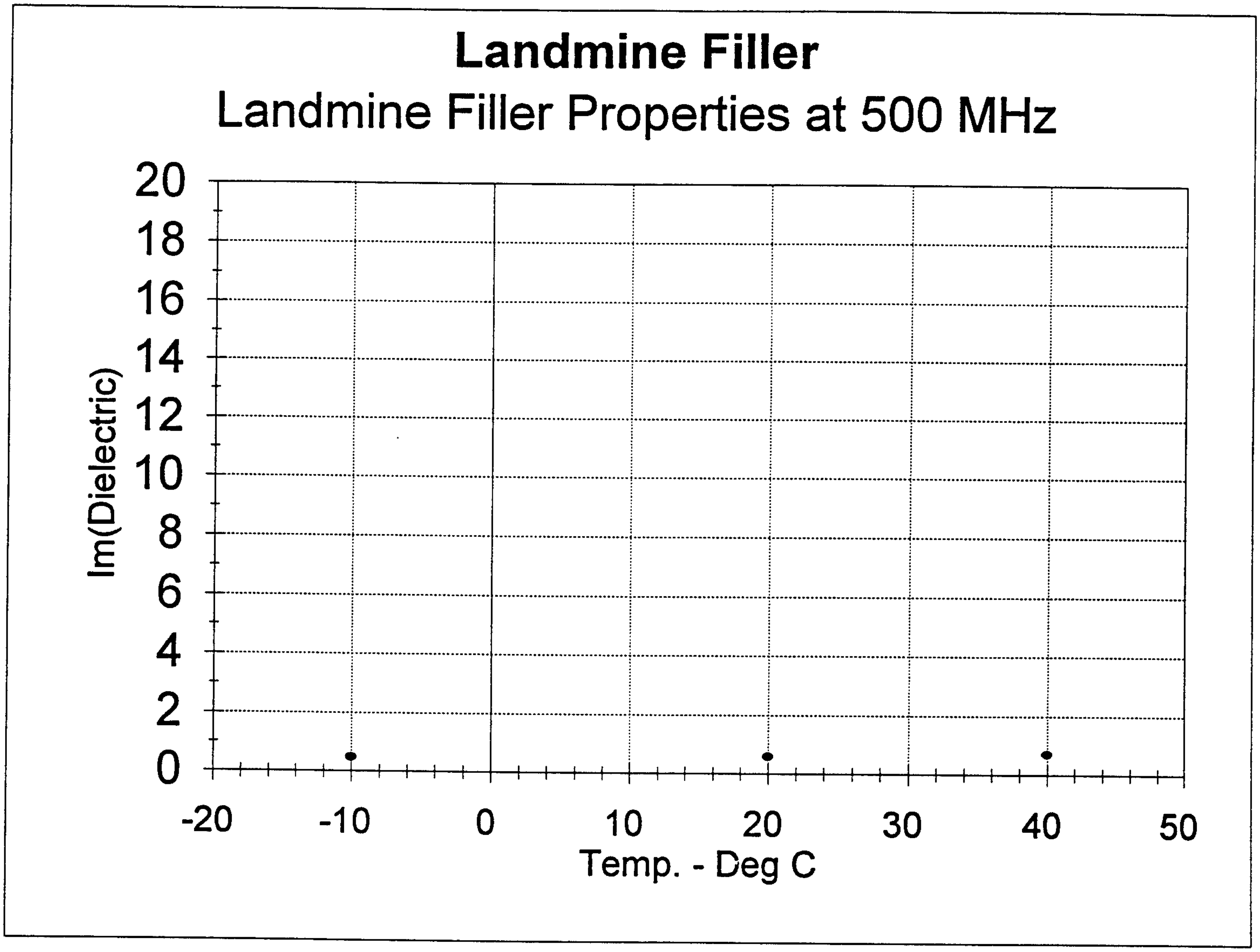

Landmine Filler
Landmine Filler Properties at 100 MHz
Loss Tangent
10
1
0.1
0.01
0.001
-20
-10
0
10
20
30
40
50
Temp. - Deg C

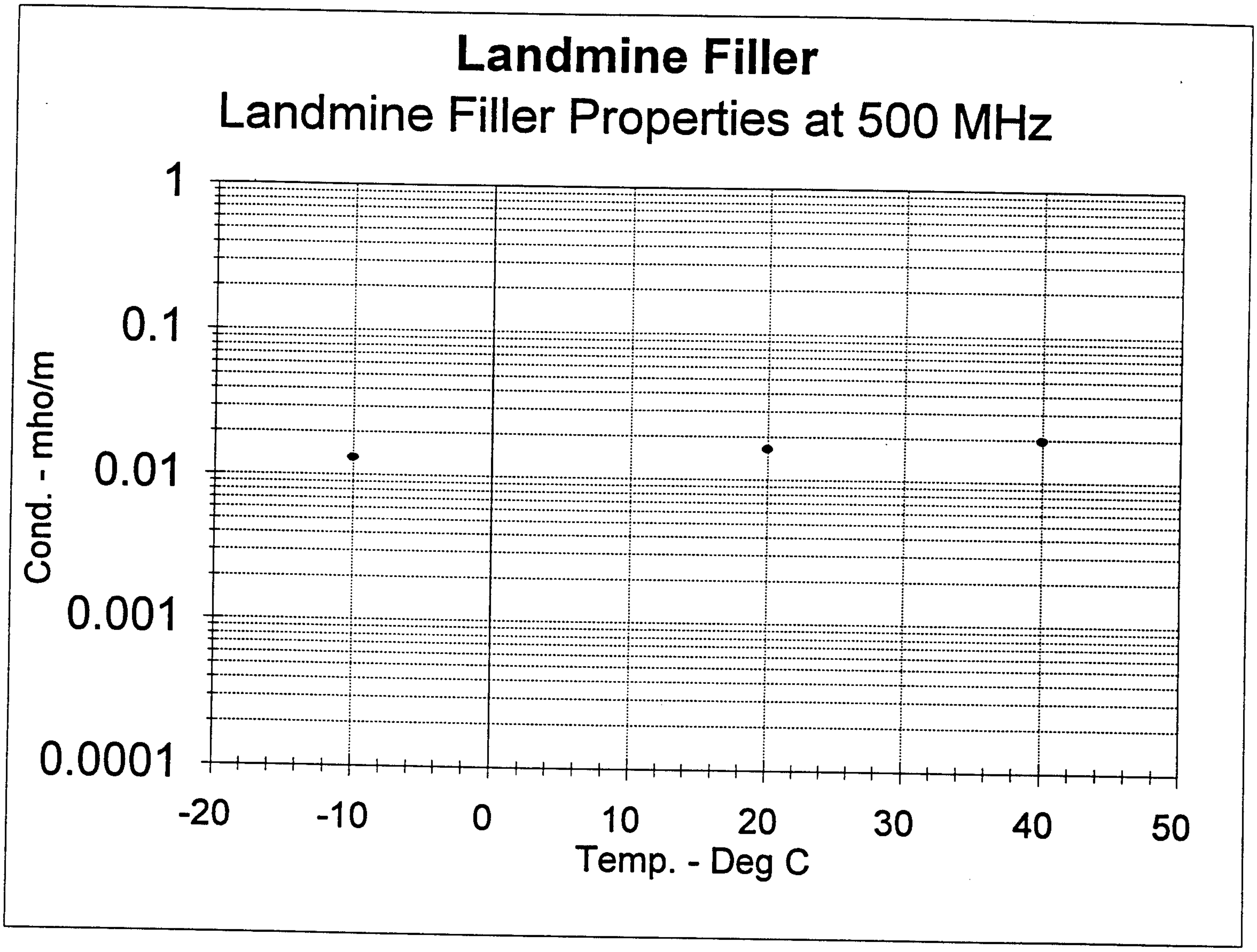

Landmine Filler
Landmine Filler Properties at 100 MHz
100
10
1
0.1
Attn. - dB/m
-20
-10
0
10
20
30
40
50
Temp. - Deg C

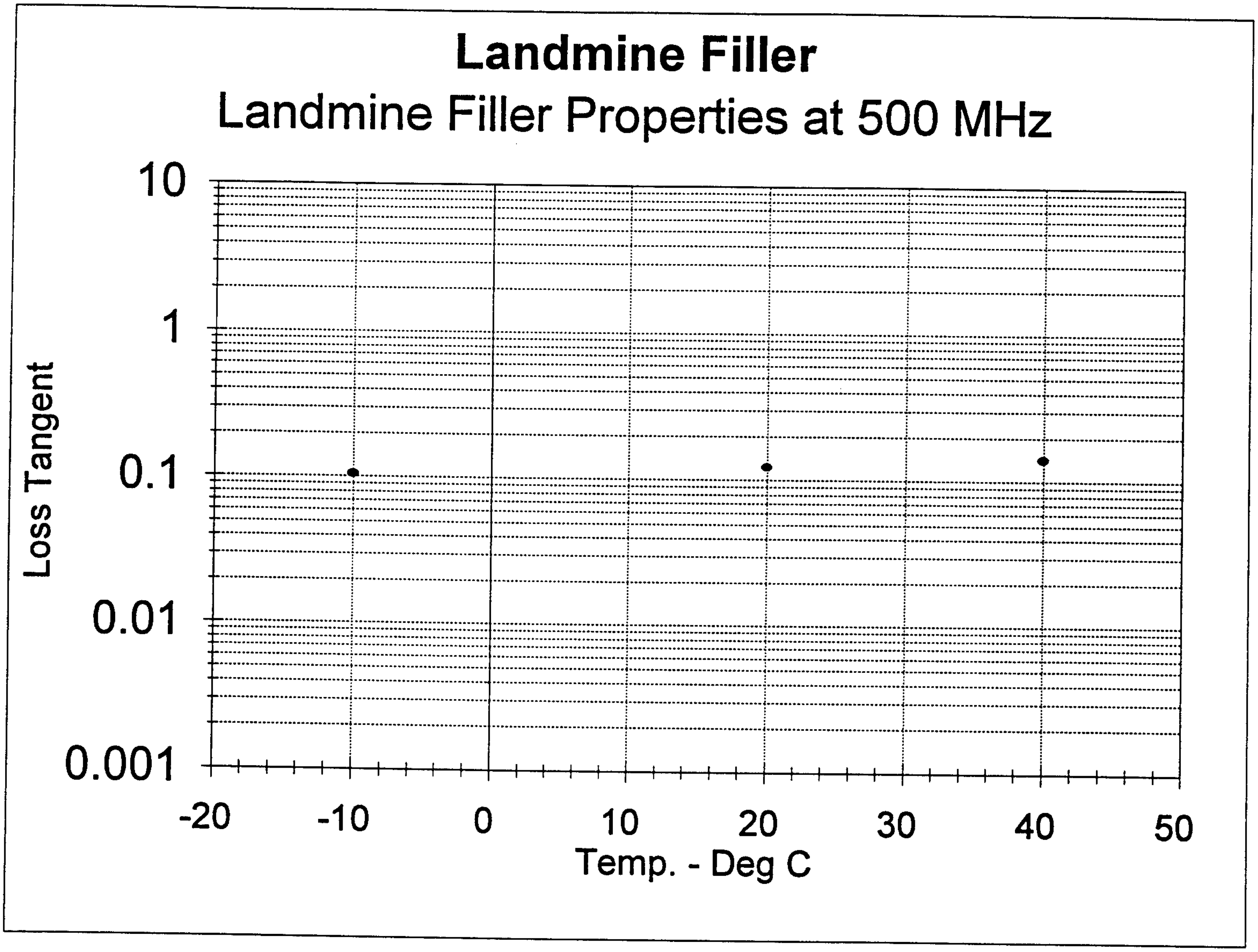


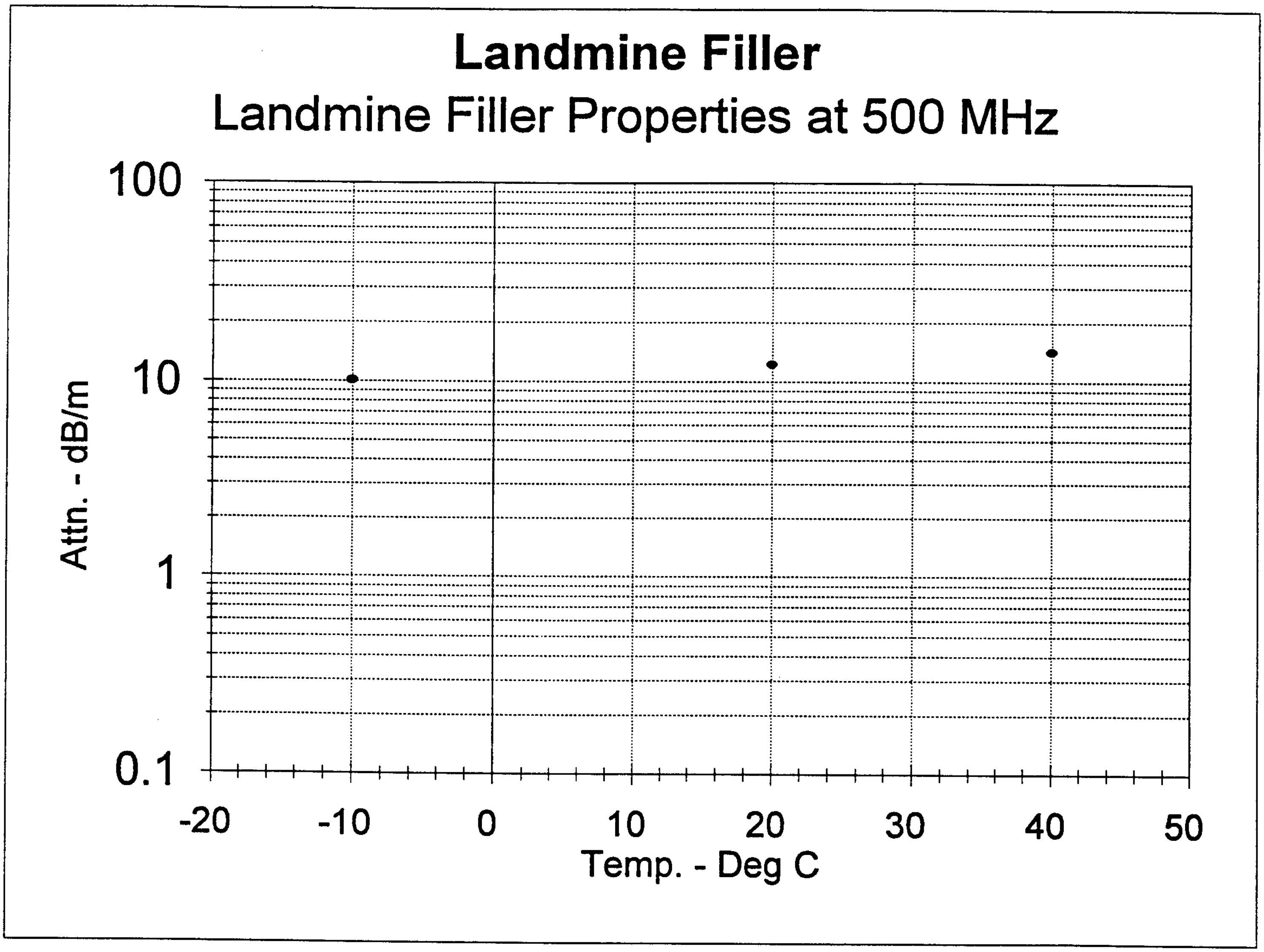
Landmine Filler
Landmine Filler Properties at 100 MHz
Norm. Velocity
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-20
-10
0
10
20
30
40
50
Temp. - Deg C

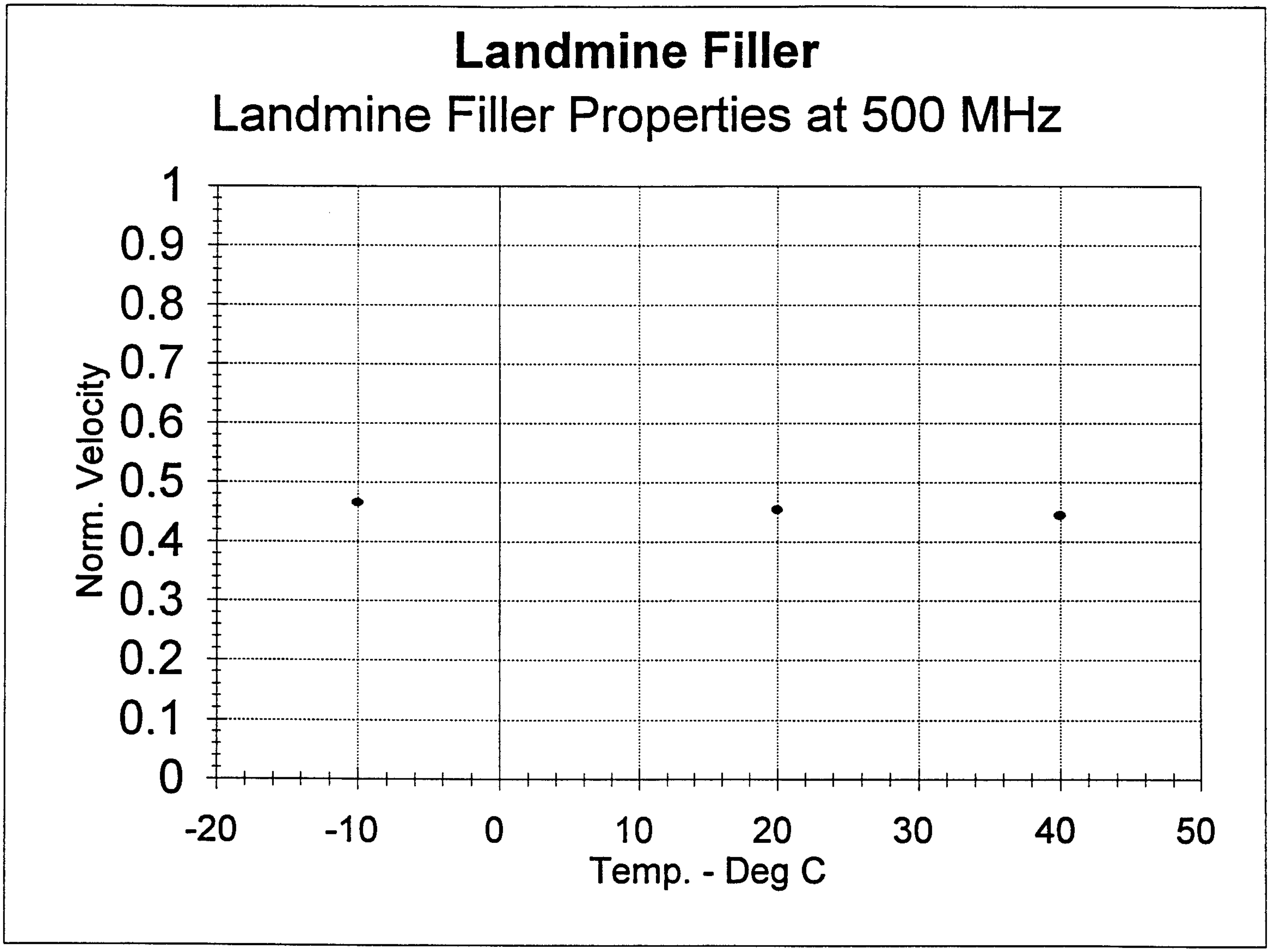

Landmine Filler
Landmine Filler Properties at 500 MHz
Re(Dielectric)
20
18
16
14
12
10
8
6
4
2
0
-20
-10
0
10
20
30
40
50
Temp. - Deg C


Landmine Filler
Landmine Filler Properties at 500 MHz
Im(Dielectric)
20
18
16
14
12
10
8
6
4
2
0
-20
-10
0
10
20
30
40
50
Temp. - Deg C


Landmine Filler
Landmine Filler Properties at 500 MHz
Cond. - mho/m
1
0.1
0.01
0.001
0.0001
-20
-10
0
10
20
30
40
50
Temp. - Deg C


Landmine Filler
Landmine Filler Properties at 500 MHz
10
1
0.1
0.01
0.001
Loss Tangent
-20
-10
0
10
20
30
40
50
Temp. - Deg C


Landmine Filler
Landmine Filler Properties at 500 MHz
100
10
1
0.1
Attn. - dB/m
-20
-10
0
10
20
30
40
50
Temp. - Deg C



Landmine Filler
Landmine Filler Properties at 500 MHz
Norm. Velocity
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-20
-10
0
10
20
30
40
50
Temp. - Deg C

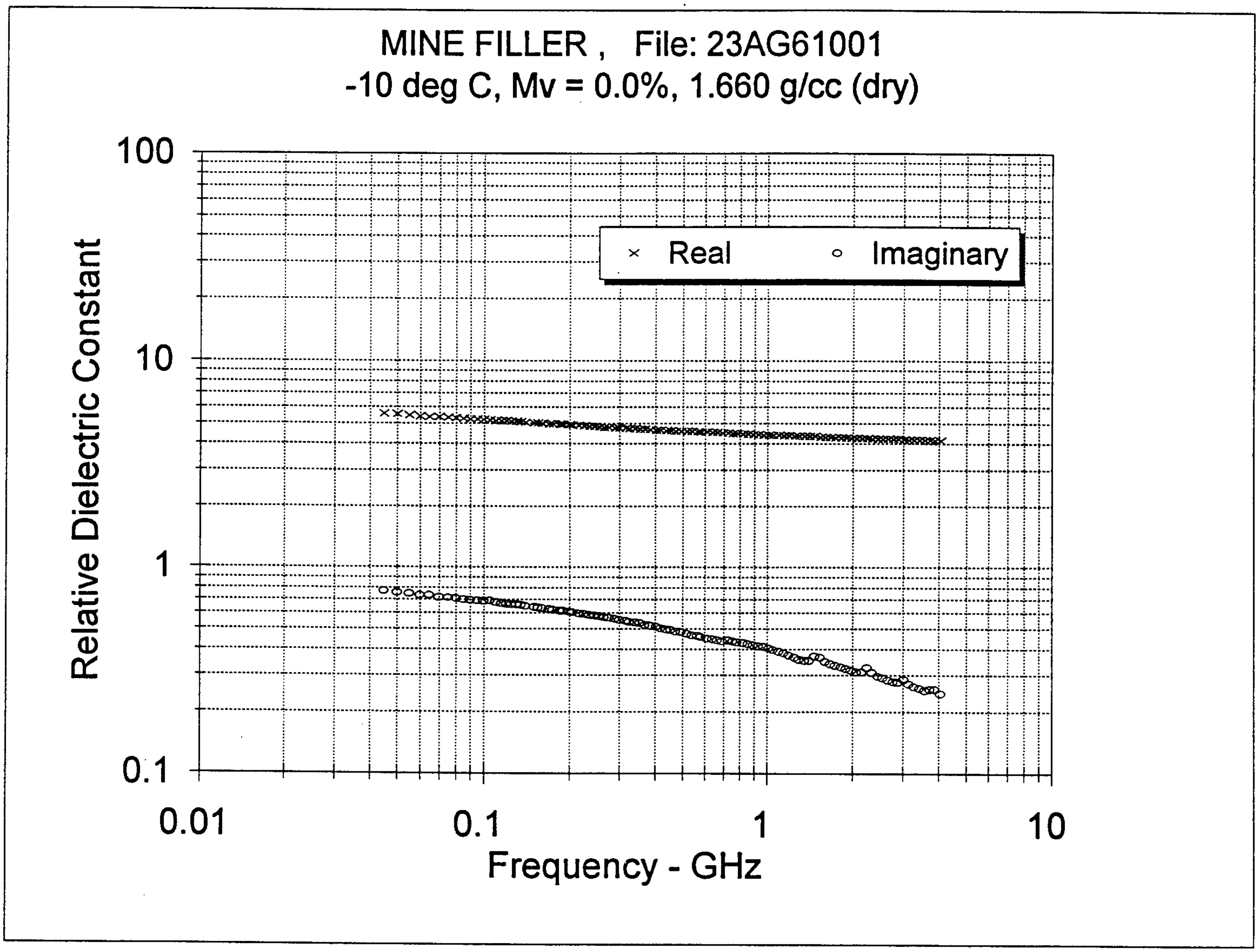
Landmine Filler
Dispersion Characteristics

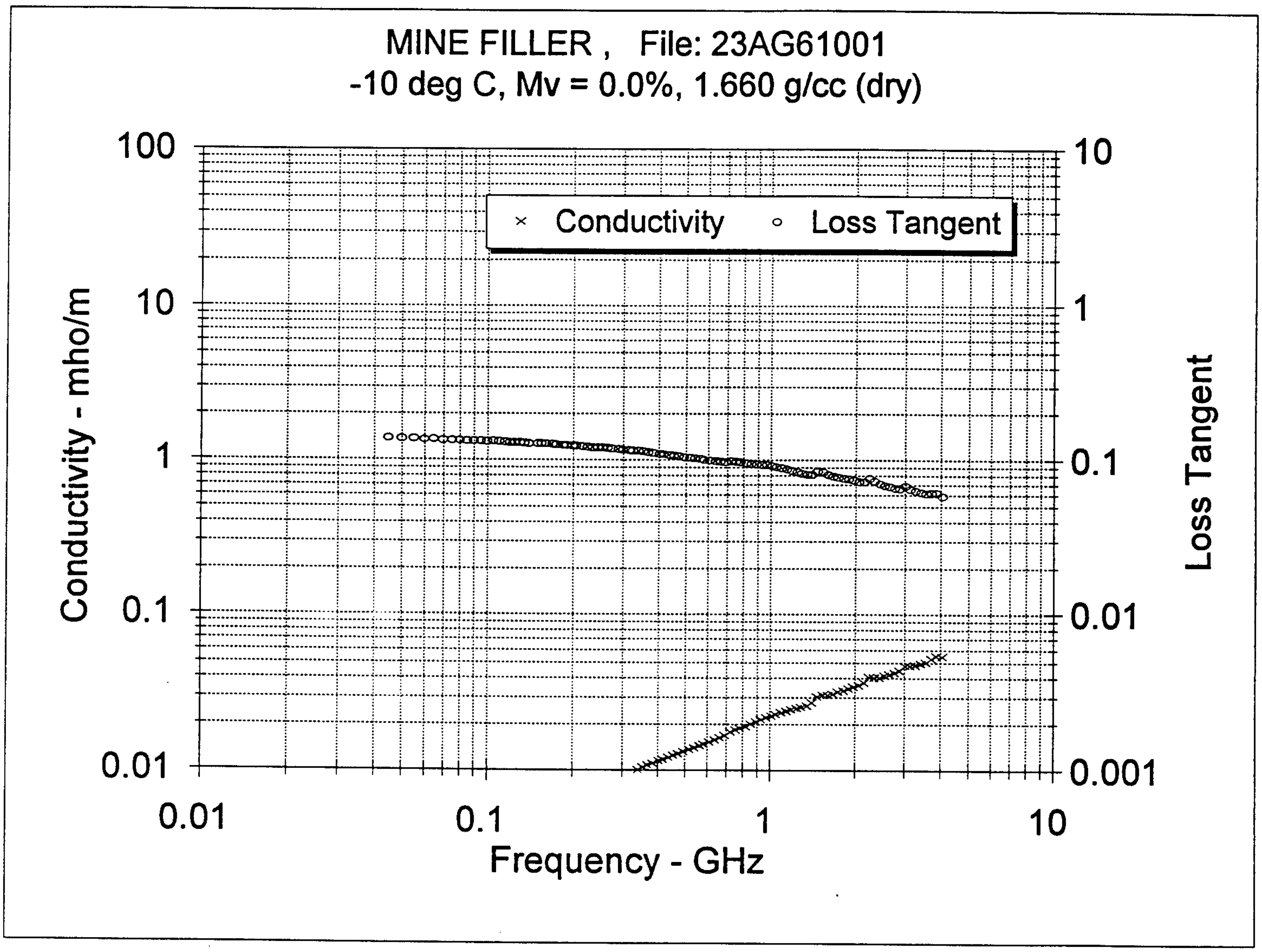
23AG61001
Mine Filler
9.7
4
0
-10
1.66

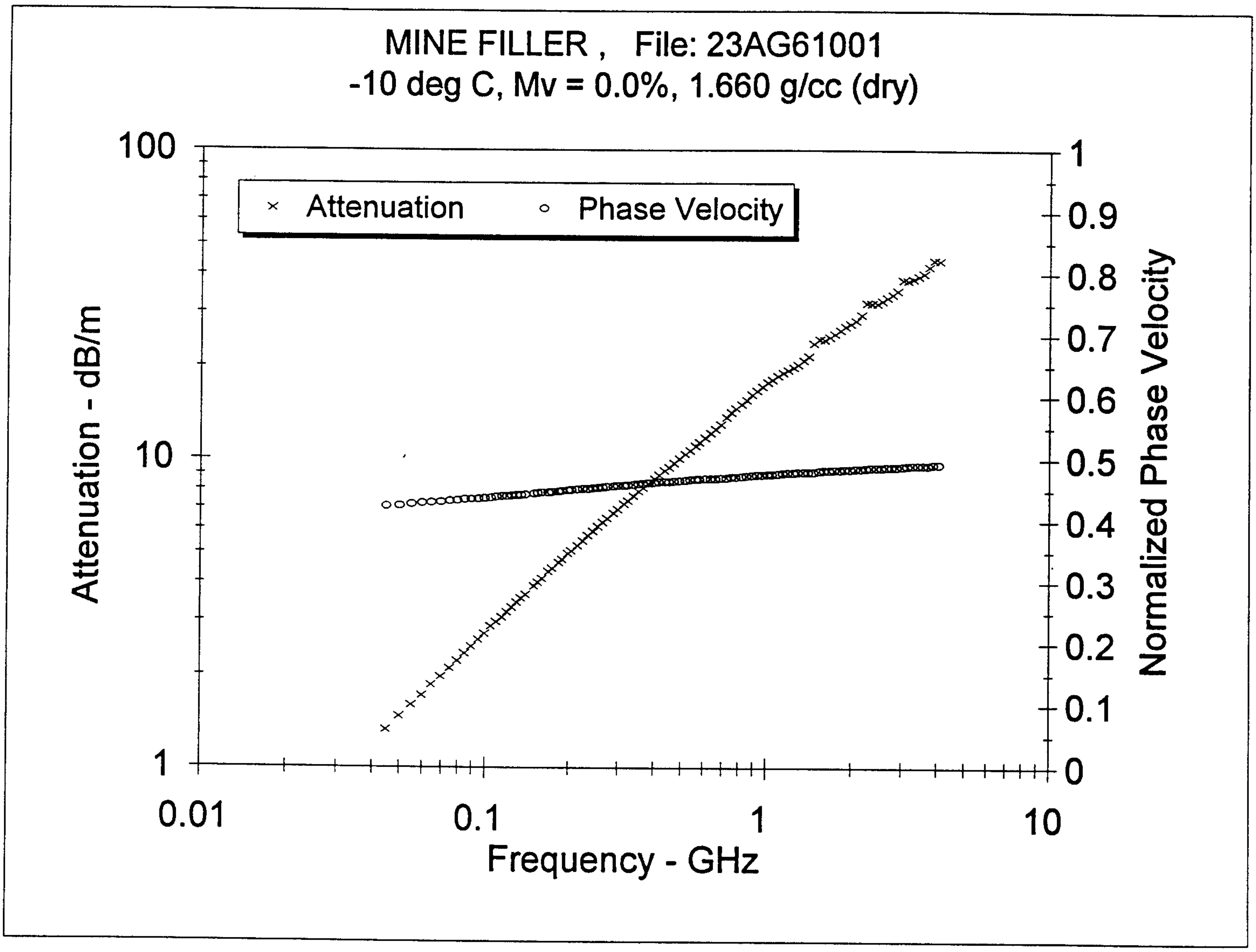
MINE FILLER , File: 23AG61001
-10 deg C, Mv = 0.0%, 1.660 g/cc (dry)

Freq	Real	Imag	Cond	Loss T	Attn	Vel
0.045	5.5292	0.7632	0.0019	0.138	1.3254	0.4243
0.05	5.4841	0.7538	0.0021	0.1374	1.4604	0.426
0.055	5.4351	0.744	0.0023	0.1369	1.5928	0.4279
0.06	5.387	0.7284	0.0024	0.1352	1.7088	0.4299
0.065	5.3702	0.7297	0.0026	0.1359	1.8574	0.4305
0.07	5.3373	0.7155	0.0028	0.1341	1.9676	0.4319
0.075	5.3053	0.7097	0.003	0.1338	2.0974	0.4332
0.08	5.2809	0.703	0.0031	0.1331	2.2211	0.4342
0.085	5.2508	0.6968	0.0033	0.1327	2.3458	0.4355
0.09	5.2275	0.6923	0.0035	0.1324	2.4734	0.4364
0.095	5.2089	0.6897	0.0036	0.1324	2.6058	0.4372
0.1	5.1842	0.6803	0.0038	0.1312	2.7117	0.4383
0.105	5.177	0.6869	0.004	0.1327	2.877	0.4385
0.11	5.1454	0.6752	0.0041	0.1312	2.972	0.4399
0.115	5.1274	0.6679	0.0043	0.1303	3.079	0.4407
0.12	5.1131	0.6647	0.0044	0.13	3.2016	0.4413
0.125	5.0917	0.6597	0.0046	0.1296	3.3169	0.4422
0.13	5.075	0.6561	0.0047	0.1293	3.4369	0.443
0.135	5.0615	0.6524	0.0049	0.1289	3.5535	0.4436
0.14	5.0447	0.6457	0.005	0.128	3.6537	0.4443
0.15	5.0171	0.6401	0.0053	0.1276	3.8914	0.4455
0.155	5.0041	0.6361	0.0055	0.1271	4.001	0.4461
0.16	4.9915	0.6326	0.0056	0.1267	4.1124	0.4467
0.17	4.9664	0.625	0.0059	0.1258	4.3281	0.4478
0.175	4.9554	0.6215	0.006	0.1254	4.4355	0.4483
0.185	4.9323	0.6141	0.0063	0.1245	4.6439	0.4494
0.19	4.9219	0.6127	0.0065	0.1245	4.7635	0.4499
0.2	4.9011	0.6059	0.0067	0.1236	4.9696	0.4508
0.205	4.8913	0.602	0.0069	0.1231	5.066	0.4513
0.215	4.8725	0.5969	0.0071	0.1225	5.2785	0.4522
0.225	4.8543	0.5908	0.0074	0.1217	5.4779	0.453
0.235	4.8383	0.5871	0.0077	0.1213	5.6944	0.4538
0.245	4.8221	0.5805	0.0079	0.1204	5.8804	0.4546
0.255	4.8068	0.5772	0.0082	0.1201	6.0959	0.4553
0.265	4.7909	0.5722	0.0084	0.1194	6.2906	0.4561
0.275	4.777	0.5677	0.0087	0.1188	6.4857	0.4567
0.29	4.7569	0.56	0.009	0.1177	6.7616	0.4577
0.3	4.7432	0.5549	0.0093	0.117	6.9402	0.4584
0.315	4.7258	0.5483	0.0096	0.116	7.2148	0.4592
0.325	4.7147	0.543	0.0098	0.1152	7.3798	0.4598
0.34	4.6983	0.5364	0.0101	0.1142	7.641	0.4606
0.355	4.687	0.5326	0.0105	0.1136	7.931	0.4612
0.37	4.6699	0.5242	0.0108	0.1122	8.1507	0.462
0.385	4.6567	0.5187	0.0111	0.1114	8.4039	0.4627
0.405	4.6409	0.5109	0.0115	0.1101	8.7237	0.4635
0.42	4.6295	0.505	0.0118	0.1091	8.9529	0.4641
0.44	4.6148	0.4975	0.0122	0.1078	9.2559	0.4648

0.455	4.6048	0.4928	0.0125	0.107	9.4899	0.4653
0.475	4.5919	0.4863	0.0128	0.1059	9.7918	0.466
0.495	4.5803	0.4804	0.0132	0.1049	10.0929	0.4666
0.52	4.5668	0.473	0.0137	0.1036	10.4549	0.4673
0.54	4.5567	0.467	0.014	0.1025	10.7318	0.4679
0.565	4.5451	0.4608	0.0145	0.1014	11.0937	0.4685
0.585	4.5364	0.4559	0.0148	0.1005	11.3752	0.4689
0.61	4.5271	0.4507	0.0153	0.0996	11.7395	0.4694
0.64	4.5166	0.4446	0.0158	0.0984	12.1646	0.47
0.665	4.5094	0.4399	0.0163	0.0976	12.5155	0.4704
0.695	4.5017	0.4369	0.0169	0.0971	13.0027	0.4708
0.725	4.492	0.4405	0.0178	0.0981	13.6899	0.4713
0.755	4.4731	0.4369	0.0183	0.0977	14.1684	0.4723
0.785	4.4609	0.432	0.0189	0.0968	14.5874	0.4729
0.82	4.4491	0.4262	0.0194	0.0958	15.0534	0.4735
0.855	4.4382	0.4222	0.0201	0.0951	15.5683	0.4741
0.895	4.4261	0.4178	0.0208	0.0944	16.147	0.4748
0.93	4.4157	0.4136	0.0214	0.0937	16.6332	0.4754
0.97	4.403	0.4088	0.0221	0.0928	17.171	0.4761
1.015	4.3893	0.4024	0.0227	0.0917	17.7157	0.4768
1.055	4.3785	0.3958	0.0232	0.0904	18.1319	0.4774
1.1	4.369	0.3897	0.0238	0.0892	18.6333	0.4779
1.15	4.3571	0.3807	0.0243	0.0874	19.0586	0.4786
1.195	4.3483	0.3729	0.0248	0.0857	19.418	0.4791
1.25	4.3394	0.3637	0.0253	0.0838	19.8324	0.4796
1.3	4.3338	0.3565	0.0258	0.0823	20.2299	0.48
1.36	4.331	0.3508	0.0265	0.081	20.8362	0.4801
1.415	4.3331	0.3503	0.0276	0.0809	21.6437	0.48
1.475	4.3247	0.3687	0.0302	0.0852	23.7622	0.4804
1.54	4.2907	0.3629	0.0311	0.0846	24.5197	0.4823
1.605	4.2809	0.3465	0.0309	0.0809	24.4253	0.4829
1.675	4.2756	0.3379	0.0315	0.079	24.8786	0.4832
1.745	4.2691	0.3326	0.0323	0.0779	25.5283	0.4836
1.82	4.262	0.3275	0.0331	0.0768	26.2396	0.484
1.9	4.2541	0.3216	0.034	0.0756	26.9278	0.4845
1.98	4.2479	0.3158	0.0348	0.0743	27.5762	0.4849
2.065	4.244	0.3101	0.0356	0.0731	28.2523	0.4851
2.155	4.2431	0.31	0.0371	0.0731	29.4792	0.4851
2.25	4.2288	0.324	0.0405	0.0766	32.2203	0.4859
2.345	4.205	0.3086	0.0402	0.0734	32.0765	0.4873
2.445	4.2008	0.2959	0.0402	0.0704	32.0856	0.4876
2.55	4.1965	0.2895	0.0411	0.069	32.7606	0.4879
2.66	4.191	0.2836	0.0419	0.0677	33.4932	0.4882
2.775	4.1874	0.2778	0.0429	0.0663	34.2484	0.4884
2.89	4.1866	0.2754	0.0443	0.0658	35.3654	0.4885
3.015	4.1777	0.2849	0.0478	0.0682	38.1986	0.489
3.145	4.1596	0.2724	0.0476	0.0655	38.1883	0.4901
3.28	4.1563	0.2635	0.0481	0.0634	38.5425	0.4903
3.42	4.152	0.2581	0.0491	0.0622	39.3778	0.4905
3.57	4.1495	0.2521	0.05	0.0608	40.172	0.4907
3.72	4.15	0.2549	0.0527	0.0614	42.3161	0.4906
3.88	4.13	0.255	0.055	0.0617	44.2643	0.4918
4.045	4.1254	0.2435	0.0548	0.059	44.0974	0.4921


MINE FILLER , File: 23AG61001
-10 deg C, Mv = 0.0%, 1.660 g/cc (dry)
Real
Imaginary
Relative Dielectric Constant
100
10
1
0.1
0.01
0.1
1
10
Frequency - GHz


MINE FILLER , File: 23AG61001
-10 deg C, Mv = 0.0%, 1.660 g/cc (dry)
Conductivity
Loss Tangent
Conductivity - mho/m
Loss Tangent
Frequency - GHz
100
10
1
0.1
0.01
10
1
0.1
0.01
0.001
0.01
0.1
1
10



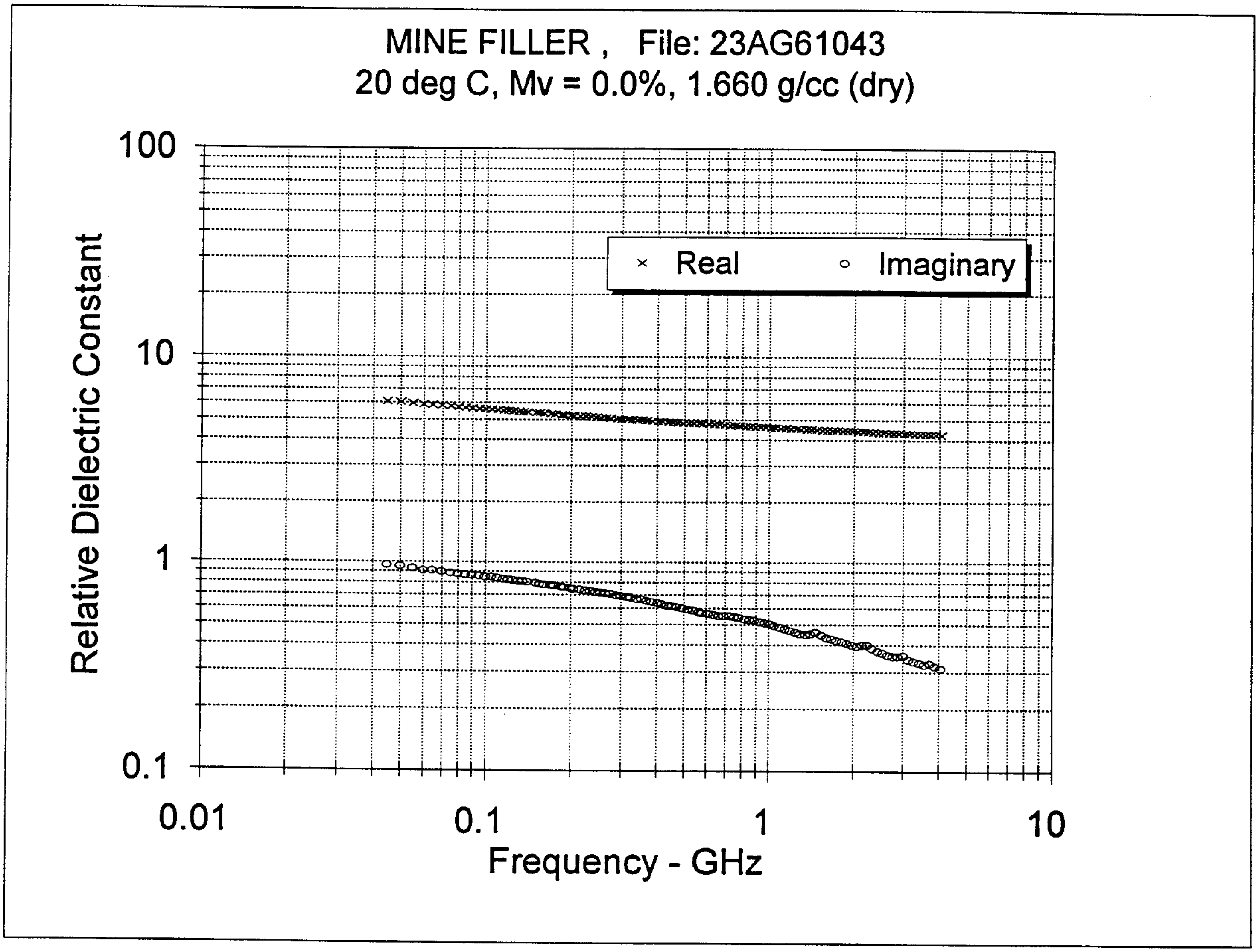
MINE FILLER , File: 23AG61001
-10 deg C, Mv = 0.0%, 1.660 g/cc (dry)
Attenuation
Phase Velocity
Attenuation - dB/m
Normalized Phase Velocity
Frequency - GHz
100
10
1
0.01
0.1
1
10
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

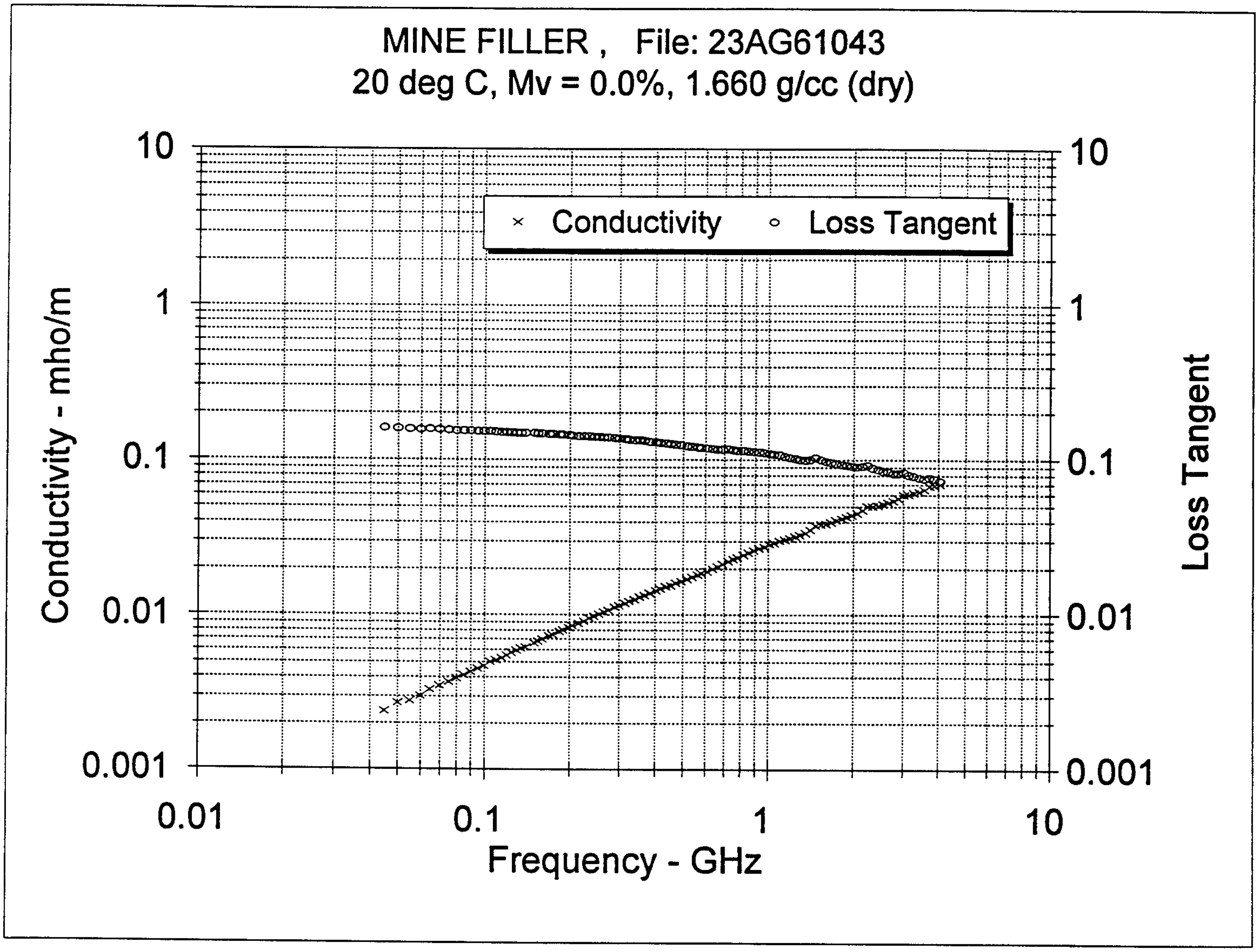
23AG61043
Mine Filler
9.7
4
0
20
1.66

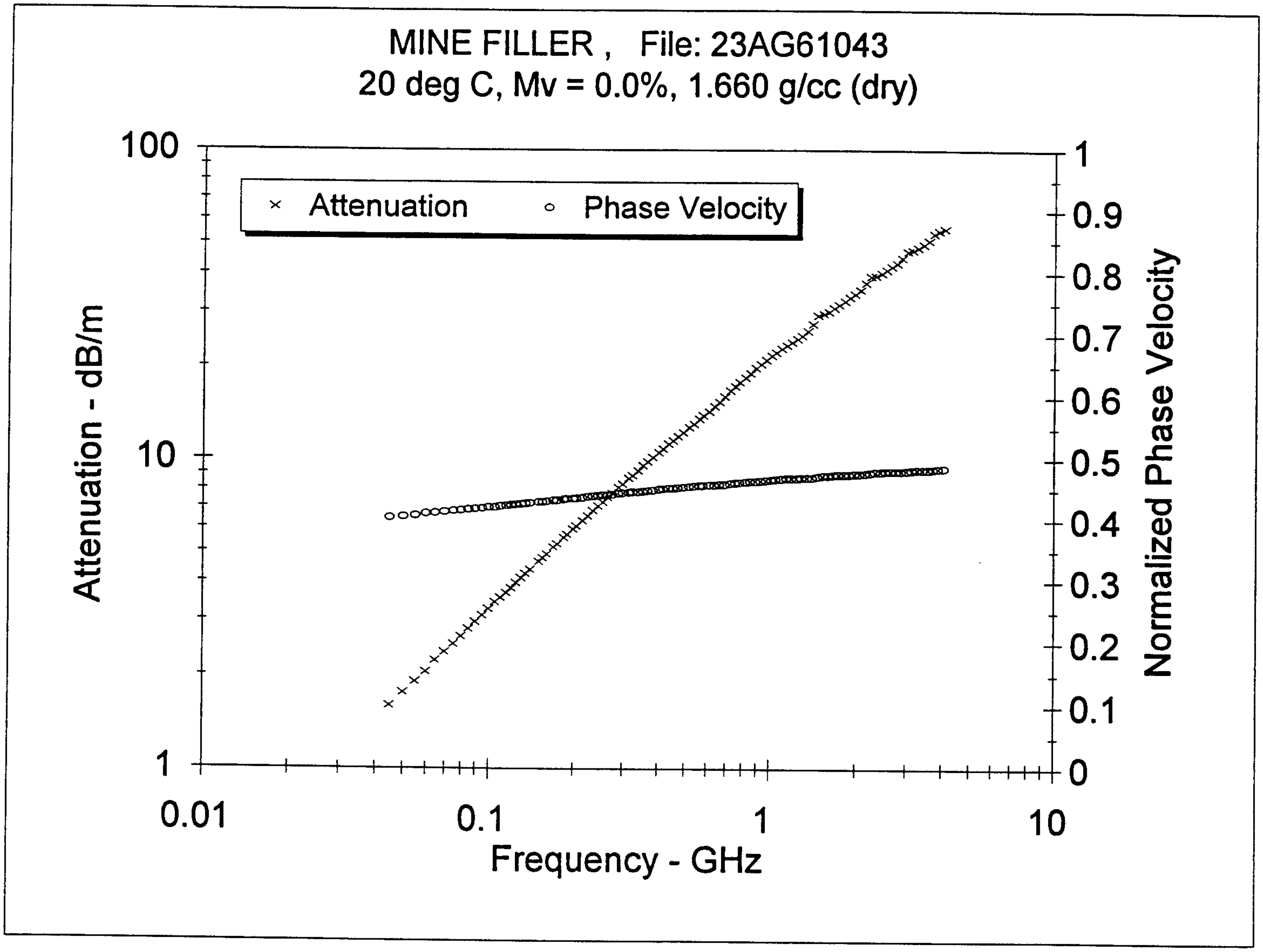
MINE FILLER , File: 23AG61043
20 deg C, Mv = 0.0%, 1.660 g/cc (dry)

Freq	Real	Imag	Cond	Loss T	Attn	Vel
0.045	6.0718	0.9668	0.0024	0.1592	1.6009	0.4046
0.05	6.0084	0.9534	0.0027	0.1587	1.7635	0.4067
0.055	5.9404	0.9315	0.0028	0.1568	1.9062	0.409
0.06	5.874	0.9107	0.003	0.155	2.0446	0.4114
0.065	5.837	0.9126	0.0033	0.1564	2.2266	0.4127
0.07	5.7924	0.8964	0.0035	0.1548	2.3644	0.4143
0.075	5.7503	0.8854	0.0037	0.154	2.5114	0.4158
0.08	5.711	0.8736	0.0039	0.153	2.6524	0.4172
0.085	5.6772	0.8688	0.0041	0.153	2.811	0.4185
0.09	5.6446	0.8619	0.0043	0.1527	2.9612	0.4197
0.095	5.6173	0.8563	0.0045	0.1524	3.1132	0.4207
0.1	5.5858	0.848	0.0047	0.1518	3.2542	0.4219
0.105	5.5687	0.8492	0.005	0.1525	3.4271	0.4225
0.11	5.5339	0.8353	0.0051	0.1509	3.5428	0.4239
0.115	5.5103	0.8268	0.0053	0.15	3.6739	0.4248
0.12	5.4866	0.8216	0.0055	0.1497	3.8177	0.4257
0.125	5.4631	0.8172	0.0057	0.1496	3.964	0.4267
0.13	5.4401	0.8107	0.0059	0.149	4.0985	0.4276
0.135	5.4217	0.8079	0.0061	0.149	4.2491	0.4283
0.14	5.4014	0.8006	0.0062	0.1482	4.3747	0.4291
0.15	5.3657	0.7908	0.0066	0.1474	4.6456	0.4305
0.155	5.3487	0.7855	0.0068	0.1469	4.7757	0.4312
0.16	5.3326	0.7818	0.007	0.1466	4.914	0.4319
0.17	5.3004	0.7721	0.0073	0.1457	5.1718	0.4332
0.175	5.2852	0.7682	0.0075	0.1454	5.3053	0.4338
0.185	5.2563	0.7594	0.0078	0.1445	5.5596	0.435
0.19	5.2419	0.7575	0.008	0.1445	5.7028	0.4356
0.2	5.2169	0.7485	0.0083	0.1435	5.9466	0.4367
0.205	5.2044	0.7433	0.0085	0.1428	6.0603	0.4372
0.215	5.1798	0.7372	0.0088	0.1423	6.3187	0.4383
0.225	5.1567	0.7303	0.0091	0.1416	6.5652	0.4393
0.235	5.1368	0.7246	0.0095	0.1411	6.8167	0.4401
0.245	5.1161	0.7172	0.0098	0.1402	7.0489	0.441
0.255	5.0992	0.7121	0.0101	0.1397	7.297	0.4418
0.265	5.0793	0.7078	0.0104	0.1394	7.5521	0.4426
0.275	5.0618	0.7022	0.0107	0.1387	7.7887	0.4434
0.29	5.0359	0.6936	0.0112	0.1377	8.1341	0.4446
0.3	5.0188	0.6868	0.0115	0.1368	8.3456	0.4453
0.315	4.9974	0.6792	0.0119	0.1359	8.6858	0.4463
0.325	4.983	0.6728	0.0122	0.135	8.8893	0.447
0.34	4.9625	0.6651	0.0126	0.134	9.2134	0.4479
0.355	4.947	0.66	0.013	0.1334	9.5603	0.4486
0.37	4.9269	0.6503	0.0134	0.132	9.8381	0.4495
0.385	4.91	0.6434	0.0138	0.131	10.1468	0.4503
0.405	4.8896	0.6345	0.0143	0.1298	10.5485	0.4513
0.42	4.8754	0.6279	0.0147	0.1288	10.8418	0.452
0.44	4.8557	0.6189	0.0151	0.1275	11.2186	0.4529

0.455	4.8433	0.6129	0.0155	0.1265	11.5025	0.4535
0.475	4.8272	0.6052	0.016	0.1254	11.877	0.4543
0.495	4.8118	0.5985	0.0165	0.1244	12.2613	0.455
0.52	4.7948	0.5895	0.017	0.1229	12.7088	0.4558
0.54	4.7815	0.582	0.0175	0.1217	13.0493	0.4565
0.565	4.7668	0.575	0.0181	0.1206	13.5111	0.4572
0.585	4.7555	0.5694	0.0185	0.1197	13.8698	0.4578
0.61	4.7428	0.5632	0.0191	0.1187	14.3239	0.4584
0.64	4.7292	0.5564	0.0198	0.1177	14.8688	0.459
0.665	4.7193	0.5516	0.0204	0.1169	15.3319	0.4595
0.695	4.7075	0.5502	0.0213	0.1169	16.0027	0.4601
0.725	4.6903	0.5507	0.0222	0.1174	16.7413	0.461
0.755	4.6703	0.5432	0.0228	0.1163	17.2311	0.462
0.785	4.657	0.5383	0.0235	0.1156	17.7815	0.4626
0.82	4.6417	0.5318	0.0242	0.1146	18.3795	0.4634
0.855	4.6283	0.5272	0.0251	0.1139	19.0255	0.4641
0.895	4.613	0.5216	0.026	0.1131	19.74	0.4649
0.93	4.5995	0.5161	0.0267	0.1122	20.3244	0.4655
0.97	4.5846	0.5099	0.0275	0.1112	20.9802	0.4663
1.015	4.568	0.5025	0.0284	0.11	21.6718	0.4672
1.055	4.5548	0.4943	0.029	0.1085	22.1919	0.4679
1.1	4.5431	0.4873	0.0298	0.1073	22.8404	0.4685
1.15	4.5283	0.4773	0.0305	0.1054	23.4311	0.4693
1.195	4.5178	0.4687	0.0311	0.1037	23.9346	0.4698
1.25	4.5066	0.4591	0.0319	0.1019	24.5584	0.4704
1.3	4.4992	0.4518	0.0327	0.1004	25.1564	0.4709
1.36	4.4942	0.4476	0.0339	0.0996	26.0881	0.4711
1.415	4.4897	0.4519	0.0356	0.1006	27.4135	0.4713
1.475	4.4664	0.4602	0.0377	0.103	29.1751	0.4725
1.54	4.4429	0.4461	0.0382	0.1004	29.6081	0.4738
1.605	4.4328	0.4339	0.0387	0.0979	30.0512	0.4744
1.675	4.4238	0.4261	0.0397	0.0963	30.8315	0.4749
1.745	4.4145	0.4199	0.0407	0.0951	31.686	0.4754
1.82	4.4049	0.4138	0.0419	0.0939	32.6003	0.4759
1.9	4.3948	0.4068	0.043	0.0926	33.4967	0.4765
1.98	4.387	0.4004	0.0441	0.0913	34.3891	0.4769
2.065	4.3813	0.3957	0.0454	0.0903	35.4735	0.4773
2.155	4.3747	0.3985	0.0478	0.0911	37.3114	0.4776
2.25	4.3509	0.4005	0.0501	0.0921	39.255	0.4789
2.345	4.3358	0.3845	0.0501	0.0887	39.3502	0.4798
2.445	4.3293	0.3745	0.0509	0.0865	39.9912	0.4802
2.55	4.3219	0.3675	0.0521	0.085	40.9606	0.4806
2.66	4.3144	0.3606	0.0533	0.0836	41.9726	0.481
2.775	4.3094	0.3545	0.0547	0.0823	43.0729	0.4813
2.89	4.3053	0.3542	0.0569	0.0823	44.8413	0.4815
3.015	4.2882	0.3564	0.0597	0.0831	47.1537	0.4825
3.145	4.2759	0.3435	0.0601	0.0803	47.4784	0.4832
3.28	4.2698	0.3357	0.0612	0.0786	48.4281	0.4836
3.42	4.2634	0.3293	0.0626	0.0772	49.5721	0.4839
3.57	4.2596	0.3242	0.0644	0.0761	50.9649	0.4842
3.72	4.2525	0.3281	0.0679	0.0772	53.7952	0.4846
3.88	4.2354	0.3199	0.069	0.0755	54.8264	0.4856
4.045	4.2297	0.311	0.07	0.0735	55.6059	0.4859


MINE FILLER , File: 23AG61043
20 deg C, Mv = 0.0%, 1.660 g/cc (dry)
Real
Imaginary
Relative Dielectric Constant
100
10
1
0.1
0.01
0.1
1
10
Frequency - GHz


MINE FILLER , File: 23AG61043
20 deg C, Mv = 0.0%, 1.660 g/cc (dry)
Conductivity
Loss Tangent
Conductivity - mho/m
Loss Tangent
Frequency - GHz
10
1
0.1
0.01
0.001
0.01
0.1
1
10

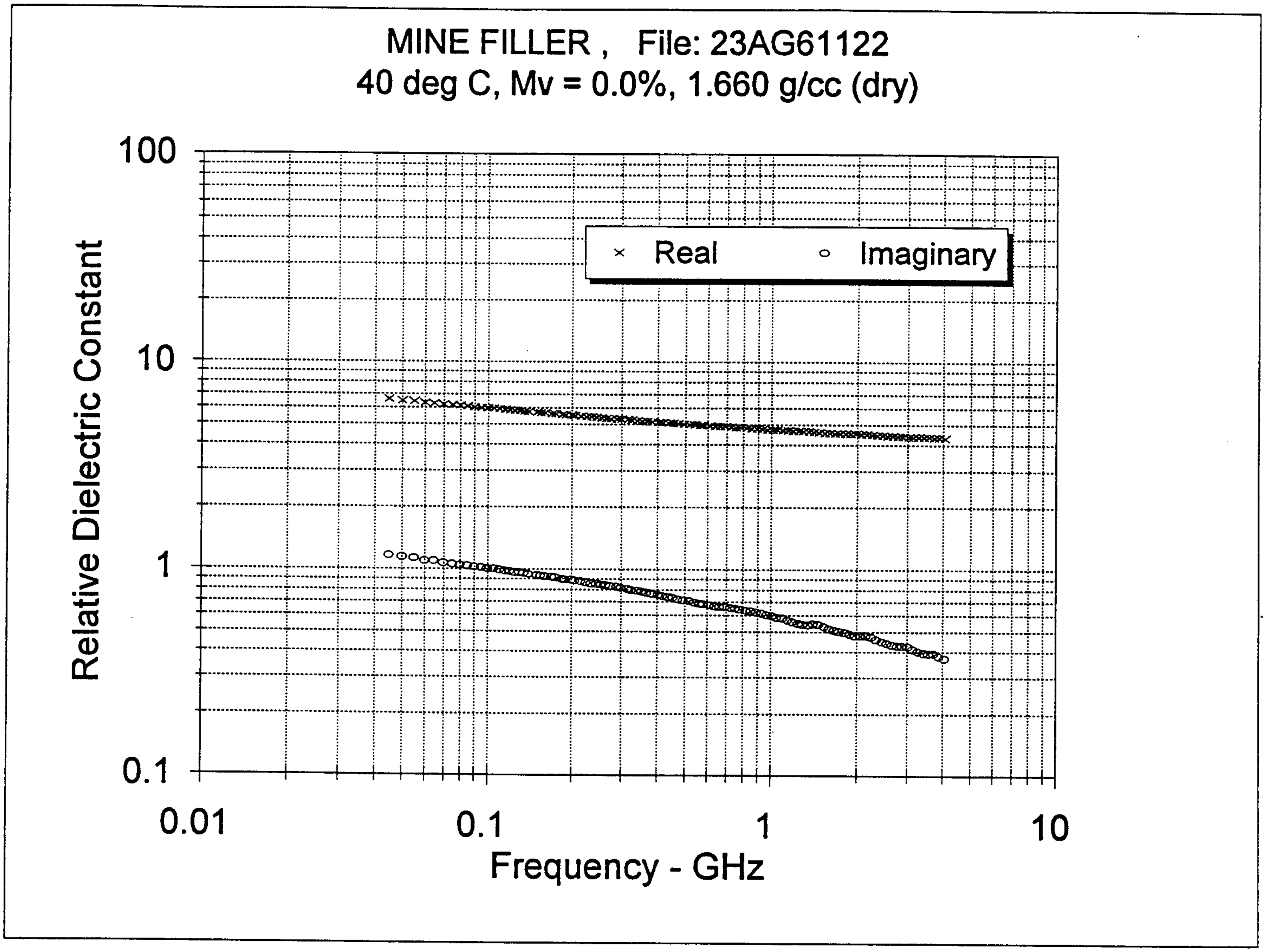

MINE FILLER , File: 23AG61043
20 deg C, Mv = 0.0%, 1.660 g/cc (dry)
Attenuation
Phase Velocity
Attenuation - dB/m
100
10
1
Normalized Phase Velocity
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.01
0.1
1
10
Frequency - GHz

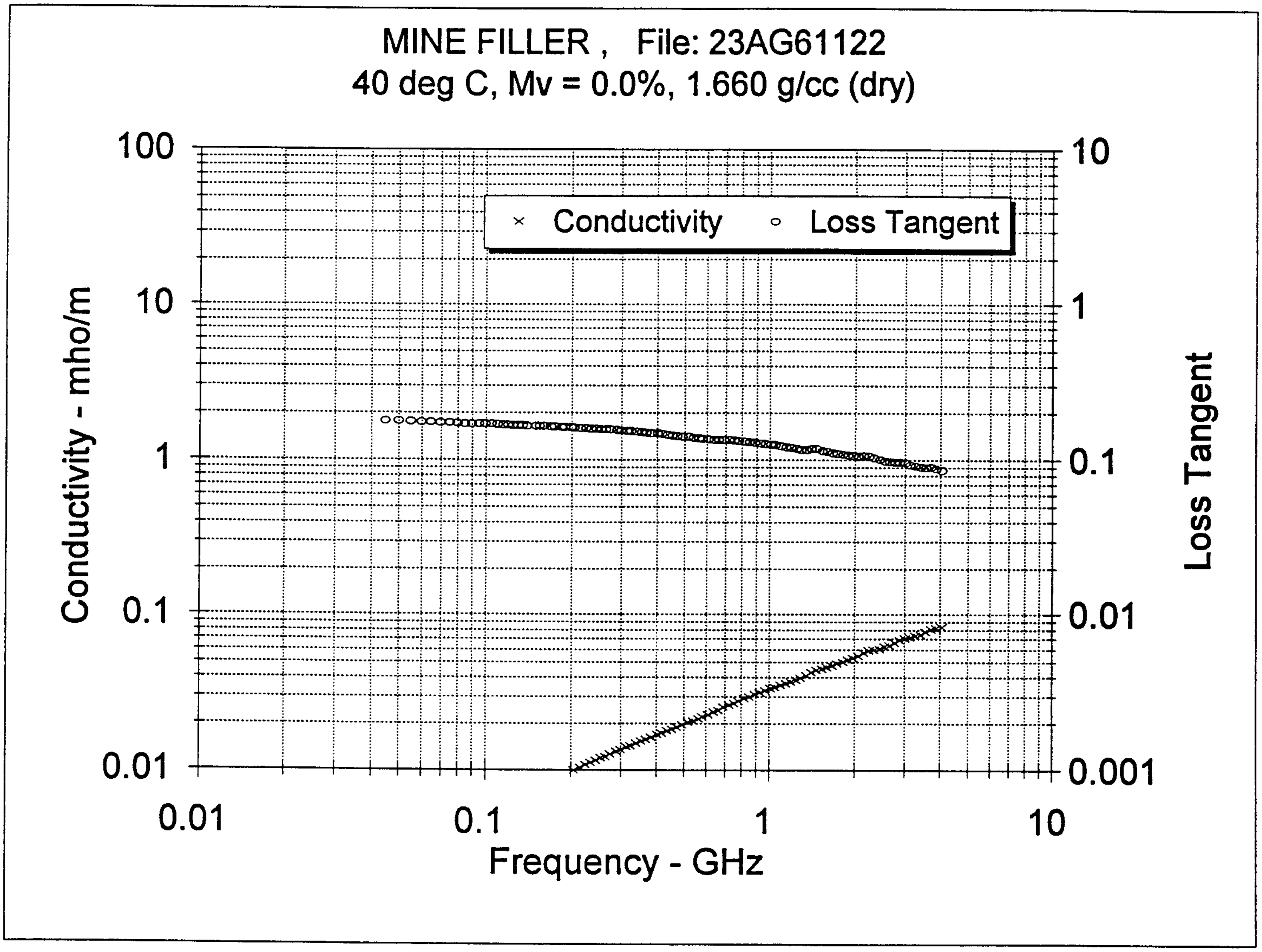
23AG61122
Mine Filler
9.7
4
0
40
1.66

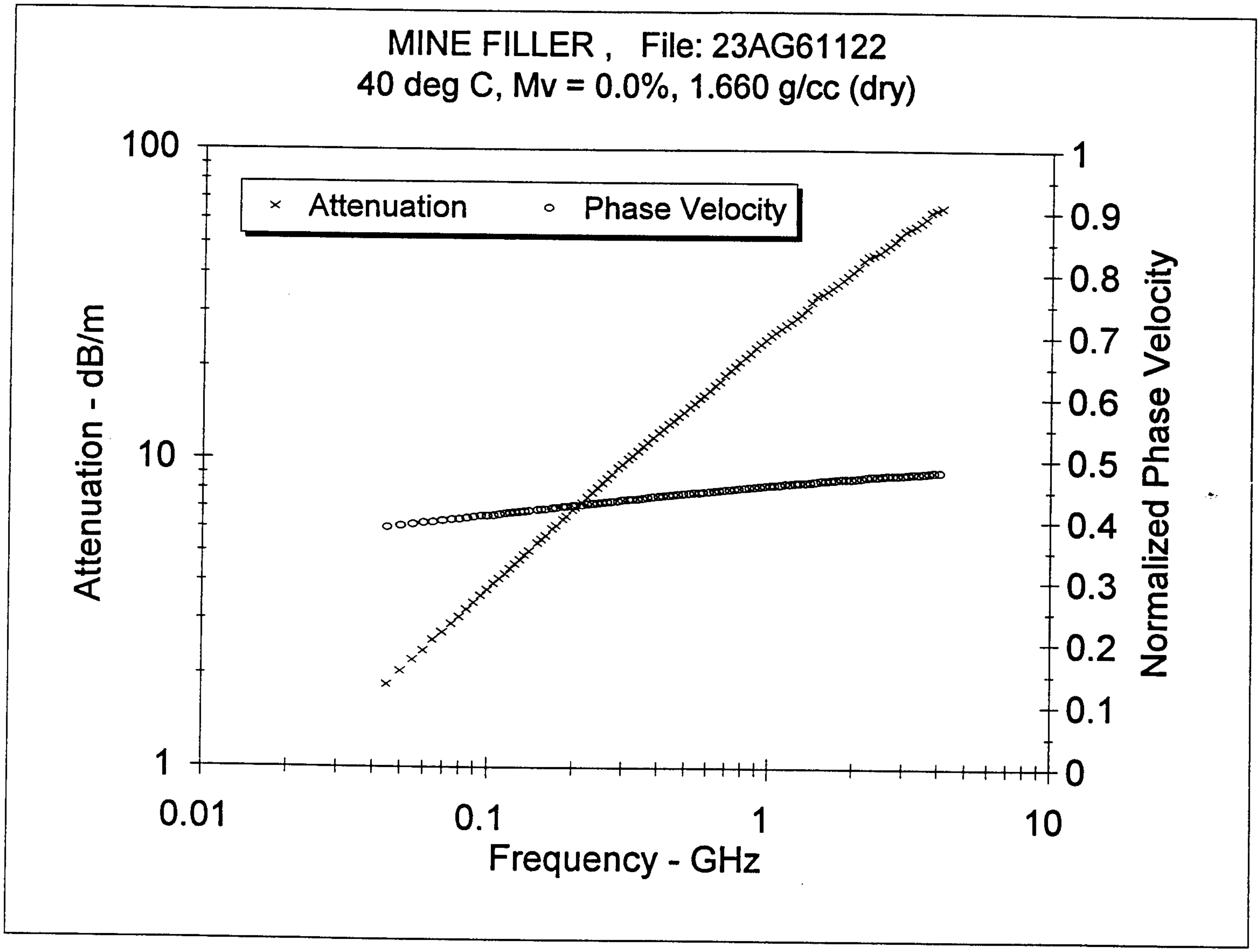
MINE FILLER , File: 23AG61122
40 deg C, Mv = 0.0%, 1.660 g/cc (dry)

Freq	Real	Imag	Cond	Loss T	Attn	Vel
0.045	6.5505	1.1573	0.0029	0.1767	1.8437	0.3892
0.05	6.4695	1.1418	0.0032	0.1765	2.0337	0.3916
0.055	6.3812	1.1228	0.0034	0.176	2.2151	0.3944
0.06	6.2952	1.0949	0.0037	0.1739	2.3728	0.3971
0.065	6.2569	1.0925	0.0039	0.1746	2.5726	0.3983
0.07	6.198	1.0664	0.0042	0.1721	2.7174	0.4002
0.075	6.1457	1.056	0.0044	0.1718	2.8952	0.4019
0.08	6.0957	1.0407	0.0046	0.1707	3.0563	0.4036
0.085	6.0544	1.0319	0.0049	0.1704	3.2307	0.405
0.09	6.0154	1.0229	0.0051	0.17	3.4019	0.4063
0.095	5.9775	1.0154	0.0054	0.1699	3.5759	0.4076
0.1	5.942	1.0076	0.0056	0.1696	3.7463	0.4088
0.105	5.9165	1.0045	0.0059	0.1698	3.93	0.4097
0.11	5.877	0.9905	0.0061	0.1685	4.0736	0.4111
0.115	5.8486	0.9815	0.0063	0.1678	4.2306	0.4121
0.12	5.8227	0.9763	0.0065	0.1677	4.4008	0.413
0.125	5.7905	0.966	0.0067	0.1668	4.5486	0.4141
0.13	5.765	0.9604	0.0069	0.1666	4.7137	0.4151
0.135	5.742	0.9532	0.0072	0.166	4.8677	0.4159
0.14	5.718	0.9469	0.0074	0.1656	5.0257	0.4168
0.15	5.673	0.9367	0.0078	0.1651	5.3474	0.4184
0.155	5.6537	0.9298	0.008	0.1645	5.4948	0.4192
0.16	5.6341	0.925	0.0082	0.1642	5.6525	0.4199
0.17	5.5953	0.9145	0.0086	0.1634	5.9582	0.4214
0.175	5.579	0.9098	0.0089	0.1631	6.1112	0.422
0.185	5.543	0.8989	0.0092	0.1622	6.4042	0.4234
0.19	5.5265	0.895	0.0095	0.162	6.5583	0.424
0.2	5.4966	0.8865	0.0099	0.1613	6.8566	0.4252
0.205	5.4804	0.8808	0.01	0.1607	6.9931	0.4258
0.215	5.4528	0.873	0.0104	0.1601	7.2883	0.4269
0.225	5.4251	0.8645	0.0108	0.1594	7.5723	0.428
0.235	5.4017	0.8581	0.0112	0.1589	7.867	0.4289
0.245	5.3762	0.8493	0.0116	0.158	8.1372	0.43
0.255	5.3584	0.8445	0.012	0.1576	8.4356	0.4307
0.265	5.3346	0.8381	0.0123	0.1571	8.7197	0.4316
0.275	5.3145	0.8308	0.0127	0.1563	8.9873	0.4325
0.29	5.2834	0.8215	0.0132	0.1555	9.3993	0.4338
0.3	5.2635	0.8135	0.0136	0.1546	9.6474	0.4346
0.315	5.2385	0.8044	0.0141	0.1536	10.0411	0.4356
0.325	5.2208	0.7972	0.0144	0.1527	10.2847	0.4364
0.34	5.1966	0.7884	0.0149	0.1517	10.6653	0.4374
0.355	5.176	0.7813	0.0154	0.151	11.058	0.4383
0.37	5.1534	0.7712	0.0159	0.1497	11.4022	0.4393
0.385	5.1331	0.7634	0.0163	0.1487	11.768	0.4402
0.405	5.1081	0.7533	0.017	0.1475	12.2458	0.4413
0.42	5.0908	0.7457	0.0174	0.1465	12.5922	0.442
0.44	5.0682	0.7355	0.018	0.1451	13.0404	0.443

0.455	5.0532	0.7283	0.0184	0.1441	13.3744	0.4437
0.475	5.0332	0.7195	0.019	0.143	13.8212	0.4446
0.495	5.0153	0.7115	0.0196	0.1419	14.2686	0.4454
0.52	4.9945	0.7016	0.0203	0.1405	14.8122	0.4464
0.54	4.9786	0.6936	0.0208	0.1393	15.2316	0.4471
0.565	4.9606	0.6855	0.0215	0.1382	15.7806	0.4479
0.585	4.9467	0.6788	0.0221	0.1372	16.2014	0.4486
0.61	4.9313	0.6721	0.0228	0.1363	16.7547	0.4493
0.64	4.9144	0.665	0.0237	0.1353	17.4242	0.4501
0.665	4.9015	0.6606	0.0244	0.1348	18.0083	0.4507
0.695	4.8836	0.6593	0.0255	0.135	18.8178	0.4515
0.725	4.862	0.6552	0.0264	0.1348	19.5521	0.4525
0.755	4.8405	0.6458	0.0271	0.1334	20.1134	0.4535
0.785	4.8253	0.6404	0.028	0.1327	20.772	0.4542
0.82	4.807	0.633	0.0289	0.1317	21.4867	0.4551
0.855	4.7912	0.627	0.0298	0.1309	22.2305	0.4559
0.895	4.7726	0.6197	0.0308	0.1299	23.0455	0.4568
0.93	4.7568	0.6131	0.0317	0.1289	23.7307	0.4576
0.97	4.7392	0.6057	0.0327	0.1278	24.5	0.4584
1.015	4.7198	0.5966	0.0337	0.1264	25.3034	0.4594
1.055	4.7048	0.5875	0.0345	0.1249	25.9419	0.4601
1.1	4.6911	0.5796	0.0355	0.1236	26.7239	0.4608
1.15	4.6742	0.5683	0.0363	0.1216	27.4472	0.4617
1.195	4.6618	0.5593	0.0372	0.12	28.1073	0.4623
1.25	4.6484	0.5493	0.0382	0.1182	28.9159	0.463
1.3	4.6395	0.5424	0.0392	0.1169	29.7249	0.4635
1.36	4.6312	0.5402	0.0408	0.1166	30.9977	0.4639
1.415	4.6179	0.5455	0.0429	0.1181	32.6124	0.4645
1.475	4.5903	0.5431	0.0445	0.1183	33.9506	0.4659
1.54	4.5704	0.528	0.0452	0.1155	34.5367	0.467
1.605	4.5587	0.5167	0.0461	0.1133	35.274	0.4676
1.675	4.547	0.508	0.0473	0.1117	36.2408	0.4682
1.745	4.5356	0.5009	0.0486	0.1104	37.2751	0.4688
1.82	4.5241	0.4936	0.05	0.1091	38.3586	0.4694
1.9	4.5124	0.486	0.0513	0.1077	39.4825	0.4701
1.98	4.503	0.4796	0.0528	0.1065	40.6475	0.4706
2.065	4.4947	0.4762	0.0547	0.1059	42.1287	0.471
2.155	4.4805	0.4791	0.0574	0.1069	44.3001	0.4718
2.25	4.4556	0.4715	0.059	0.1058	45.6542	0.4731
2.345	4.4426	0.457	0.0596	0.1029	46.1861	0.4738
2.445	4.4341	0.447	0.0608	0.1008	47.148	0.4743
2.55	4.4248	0.4391	0.0623	0.0992	48.3586	0.4748
2.66	4.4159	0.4316	0.0638	0.0977	49.6344	0.4753
2.775	4.4092	0.4261	0.0658	0.0966	51.1631	0.4757
2.89	4.4002	0.4267	0.0686	0.097	53.4056	0.4762
3.015	4.3805	0.422	0.0707	0.0963	55.2254	0.4772
3.145	4.3693	0.4094	0.0716	0.0937	55.972	0.4779
3.28	4.3612	0.4011	0.0732	0.092	57.2479	0.4783
3.42	4.3536	0.3941	0.075	0.0905	58.6994	0.4788
3.57	4.348	0.39	0.0774	0.0897	60.6804	0.4791
3.72	4.3347	0.3912	0.0809	0.0902	63.513	0.4798
3.88	4.3197	0.3802	0.082	0.088	64.489	0.4807
4.045	4.3127	0.3712	0.0835	0.0861	65.6972	0.4811


MINE FILLER , File: 23AG61122
40 deg C, Mv = 0.0%, 1.660 g/cc (dry)
Relative Dielectric Constant
100
10
1
0.1
0.01
0.1
1
10
Frequency - GHz
Real
Imaginary


MINE FILLER , File: 23AG61122
40 deg C, Mv = 0.0%, 1.660 g/cc (dry)
Conductivity
Loss Tangent
Conductivity - mho/m
Loss Tangent
Frequency - GHz
100
10
1
0.1
0.01
0.001
0.01
0.1
1
10



MINE FILLER , File: 23AG61122
40 deg C, Mv = 0.0%, 1.660 g/cc (dry)
Attenuation
Phase Velocity
Attenuation - dB/m
Normalized Phase Velocity
Frequency - GHz
100
10
1
0.01
0.1
1
10
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1